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APOLLO SERVICE MODULE ROCKET ENGINE (u)

Monthly Progress Report

Report 3865-01-22 | 29 May 1964

N79-76555

(NASA-CR-118582) APOLLO SERVICE MODULE ROCKET ENGINE MONTHLY PROGRESS REPORT (Aerojet-General Corp., Sacramento, Calif.) 75 p

Unclas 00/20 11635

FF No. [redacted] (NASA CR OR TMX OR AD NUMBER) (CATEGORY)

[redacted] AND NASA RESEARCH CENTERS [redacted]

AEROJET GENERAL TIRE GENERAL

AEROJET-GENERAL CORPORATION

[redacted]

C65-7072

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APOLLO SERVICE MODULE ROCKET ENGINE (u)

MONTHLY PROGRESS REPORT

Report 3865-01-22

Purchase Order M3J7XA-406014

(MC 999-0025A, 3.4.2) and (S&ID MR-3)

Prepared for

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FOREWORD

This is the twenty-second in a series of monthly progress reports submitted in partial fulfillment of Purchase Order M3J7XA-406014, NAA S&ID.

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I. INTRODUCTION

Authorization to proceed on the Apollo Service Module Rocket Engine Program was received from North American Aviation, Inc., Space and Information Systems Division on 9 April 1962. The formal notice of contract award for Letter Contract M2H43X-406014, dated 30 April 1962, followed this authorization. The definitive contract, Purchase Order M3J7XA-406014, was executed on 18 February 1964.

II. ENGINEERING

A. THRUST CHAMBER

1. Full-Scale Ablative Chamber

a. Chambers with a 1.5:1 Exit Area Ratio

During this report period three lightweight edgegrain and one lightweight cloth chamber were tested. The test data for these chambers are tabulated below:

Chamber Type and SN	Test Type and Duration	Throat Area Increase, %	Remarks
Lightweight Edgegrain A-15	P_c Survey, five 5-sec runs, modified incremental duty cycle 947.9 sec	4.35	The chamber was first tested with injector SN AFF-58, pattern POUL 31-10 for five 5-sec tests. A second test was conducted using injector SN AFF-27, pattern POUL 31-39 for a P_c survey. The third test was a modified incremental duration using injector SN AFF-28 and pattern POUL 31-47. The chamber is in good condition, and a char analysis is being conducted.

II, A, Thrust Chamber (cont.)

Chamber Type and SN	Test Type and Duration	Throat Area Increase, %	Remarks
Lightweight Edgegrain A-16	Mission Duty Cycle 458 sec	2.3	The chamber was tested with a 6-4-2 baffled injector, SN 0000016, pattern POUL 41-21. The test was stopped because of intermittent fluctuations in chamber pressure. The chamber had slight gouges at the baffle ends with a weak char structure over the major portion of the chamber I.D. with slight "chuffing."
Lightweight Edgegrain A-9	Injector Checkout and P_c Survey 326.5 sec	1.7	The chamber was tested for an injector checkout with injector SN AFF-32, pattern POUL 31-39. There was no evidence of streaking, gouging, or "chuffing." Two coats of lacquer were applied to the charred surface. The chamber was then cleaned per AGC Specification 46350, Level H, and subjected to a P_c survey test using injector SN AFF-32 with pattern POUL 31-43. There were no streaks or gouges and only slight "chuffing" was discernable at approximately 5 in. forward of the throat.
Lightweight Cloth	Modified Incremental Duration 750 sec	1.15	The chamber was tested with a 5-4-4 baffled injector, SN 000009, pattern POUL 41-22. The chamber was in good condition with no streaking or gouging. The char analysis is in process.

b. Chambers with a 6:1 Area Ratio

Data for the lightweight cloth 6:1 exit area ratio chamber that failed during a mission duty cycle at AEDC is being compiled. A failure analysis is in process.

II, A, Thrust Chamber (cont.)

c. Fabrication

Because of the recurrent burnthrough of cloth chambers subjected to the Apollo mission duty cycle, the chamber design has been modified to incorporate a new liner thickness. Authorization for fabrication has been issued for twelve 1.5:1 exit area ratio chambers with the new wall thickness; nine chambers will be used for prequalification testing, and three chambers will be used for the dynamically stable injector program.

A total of sixty-one 6:1 exit area ratio cloth chambers have been ordered to meet the demands of the prequalification, qualification, and deliverable chamber schedules.

d. Workhorse Chamber

Fabrication has been completed on the first of the three steel chambers for the dynamically stable injector program, and the chamber is available for injector evaluation tests.

e. Chamber Proof and Leak Test

A lightweight cloth 6:1 exit area ratio chamber was tested at the Aerojet-General Azusa facility to determine the radial deflection and the flange rotation of the chamber while being subjected to static internal gas pressurization.

Figure 1 is a photograph of the external instrumentation (dial indicator gages) located on the chamber; Table 1 is a tabulation of the dial indicator readings showing chamber deflection; and Figure 2 is a sketch of the dial indicator locations.

II, A, Thrust Chamber (cont.)

The maximum radial deflection occurred at dial indicator gage Location 11 (Figure 2) and was 0.0304 in. at a pressure of 280 psig.

The maximum permanent deformation recorded following the loading increment of 280 psig was 0.0035 in. and was also recorded at gage Location 11. The maximum rotation (clockwise) noted in the test setup (Figure 2) was 0.00115 radians.

f. Correction of Item in Last Report

In Aerojet-General Report 3865-01-21, Page 5, it was reported in error that a special proof-and-leak test procedure had been released. Correctly, a single proof-and-leak test (as described above) was conducted by structural materials personnel, using dial indicators and strain gages to detect possible dimensional changes in the chamber while being tested.

B. INJECTORS

1. Unbaffled Injectors

Testing, design effort, and data analysis with respect to solving the 600-cps combustion frequency problem was continued during this report period. Table 1 summarizes the 600-cps program activities to date.

Injector SN AFF-28 was modified with alternating film coolant orifices (similar to pattern POUL 31-37) and increased pressure drop across the pattern orifices. Steel chamber stability tests and chamber pressure (P_c) surveys with ablative chambers were conducted to investigate the effects of the modifications and the frequency dependence on chamber pressure. The data analysis is continuing but preliminary results indicate that the proposed solutions were not completely effective in eliminating the present high amplitudes associated with the 600-cps combustion frequency.

II, B, Injectors (cont.)

Flow separators in the inlet headers and smaller diameter feed tubes were added to injector SN AFF-29 with pattern POUL 31-44. The modification objectives were oriented toward the elimination of any possible interaction of flow disturbances and also toward increasing the injector pressure differential that would increase the system's attenuation. These modifications, however, did not solve the 600-cps problem.

Injector SN AFF-32 (pattern POUL 41-43) was tested with the first Helmholtz resonator made for testing to determine the actual suppression qualities of the resonator during firing conditions. Two steel-chamber tests showed that a frequency of 600-cps existed with high amplitude. The resonators on the oxidizer and fuel system were stiffened, and a chamber pressure survey was conducted from 75 to 120 psia. The resonators dampened pressure oscillations in the range of 85 psia to 120 psia. There was 400 cps operation below 85 psia chamber pressure. The fuel and oxidizer feed tubes were then braced onto the distribution-pie segments. This modification was indicated to be necessary, based on the test results of vibration laboratory testing of injector SN AFF-63. The 600-cps phenomenon was not eliminated with the addition of the distribution tube braces.

Tests of the PONX-51-11 quadlet pattern with injector SN AFF-34 were unsatisfactory because of high frequency instability. Testing was discontinued with this injector.

Injector SN AFF-32 was test-fired with monomethylhydrazine (MMH) fuel. The resonator systems were adjusted to be nonfunctional during the tests. The use of MMH as the fuel eliminated the amplified 600-cps oscillation in all tests. The results were verified by successfully conducting both steel chamber tests (5 tests of 5 sec each) and five ablative chamber tests (totaling 82 sec).

A complete discussion of the results and analyses of the total 600-cps frequency investigation is presented in Section II, K.

II, B, Injectors (cont.)

2. <u>Baffled Injectors</u>

Design and investigation concerning the BF type injectors was discontinued.

3. <u>Dynamically Stable Injector Program</u>

a. 6-4-2 Injector

The performance of the first injector (SN 0000016) after the c* test series described in the last report has been determined to be 97.2% theoretical c*. The injector pattern is POUL 41-21. The evaluation of the injector was continued by conducting two 150 grain, nondirected pulse charge tests and 5 ablative chamber compatibility tests. The induced pressure spike was 67 psi above nominal chamber pressure, and recovery took place within 25 millisec (0.025). Minor nicks were sustained on the injector face and baffles because of the pulse charge fragments. The five ablative test firings totaled 458 sec. There were two minor streaks in the throat area of the ablative chamber. The throat area increase was 2% during the 458 sec of ablative testing.

Slight chamber pressure perturbations were noted on the tests that followed the first pulse test. An intermanifold leak test determined leakage to exist at the root of the face ring welds in areas where oxidizer orifices had been drilled. Two unsuccessful attempts were made to repair-weld the leaking areas. The current plans for the injector include a metallurgical analysis of all weld joints for evaluation and determination of future welding techniques.

The second injector (SN 0000017) is complete and will be evaluated with c*, pulse, and compatibility tests during the next report period. Leakage of the type noted for injector SN 0000016 was also present with this injector. Both injectors were drilled with the same orifice pattern. This condition was successfully corrected by vacuum impregnating the leak areas with an

II, B, Injectors (cont.)

aluminum-lithium compound. The leakage problem is caused by a combination of insufficient weld root penetration of the face ring welds and oxidizer orifices that pass too close to the face-ring weld areas. Allowances have been made for weld joint variances in future orifice patterns for all remaining injectors in order to eliminate this leakage.

Eight additional injectors are in various stages of fabrication and will be evaluated with c*, pulse, and compatibility tests as they become available.

b. 5-4-4 Injector

The first two 5-4-4 injectors have been completed. The first injector (SN 0000009) has successfully completed three steel chamber balance tests, two pulse tests, and seven ablative chamber compatibility tests (totaling 752 sec). The injector was recovered from centrally mounted, 157 grain pulse charges in less than 10 millisec. Pressure perturbations in excess of 200 psi were measured. The injector-chamber compatibility tests were successful with only minor streaking near the forward end of the chamber and a total area increase of 1.15%. Additional testing will be conducted during the next report period to determine the injector performance with pattern POUL 41-22.

The second injector, SN 0000006, has successfully completed a balance test and has recovered from a 157 grain pulse charge. Pulse tests, ablative chamber compatibility tests, and c* tests will also be conducted during the next report period. This injector has a pattern identical to the first unit, POUL 41-22.

Eight additional injectors are in various phases of fabrication. Pattern selection has been made for three of these. Testing to evaluate stability, compatibility, and performance will be conducted as the injectors become available.

II, Engineering (cont.)

C. NOZZLE

1. General

Tooling for the 40:1 prequalification nozzle (in which the columbium section extends to the 40:1 area ratio point) is progressing satisfactorily. Eight segments of the bulge die have been cast, and preliminary machining has been accomplished. The eight segments will be bolted together and final-machined to contour. Completion is scheduled for the first week in June.

Application of the rhenium to the copper backup tooling to prevent porosity previously encountered as a result of chrome-plating flaking appears to be successful. While efforts are being made to reduce the cost of the rhenium solution, a new method of chrome plating is being used on the new copper tooling.

2. Leak Check Test

A leak test was performed on the thrust chamber-nozzle extension attachment joint. The bolts were torqued to the requirements of AGC Specification 46659. Gaseous nitrogen of 5.0 psig was applied with no evidence of leakage. The metallic seal that was used on the modified J-design unit tested at AEDC was examined microscopically, and there was no evidence of leakage in any of the areas inspected. Emphasis was placed on examining the areas between the bolts. The method of analysis is checking the soft nickel plating on the sealing edge. It can be determined by the condition of this nickel whether or not the seal was adequately troqued initially and whether or not hot gas leaked by the seal. The seal design has been finalized. This design will have a 0.010-in. total deflection and will require 130 lb/in. loading. This loading requirement can easily be met with the existing 48-bolt attachment technique.

II, C, Nozzle (cont.)

3. Materials

Columbium sheet fabrication by the Wah Chang Corporation, Albany, Oregon, is becoming progressively more successful. ASTM grain sizes of 9 are becoming typical, and mechanical properties have increased, with recent tests of several production ingots yielding consistent results. Previously,grain sizes for sheet stock were as low as ASTM 4.

The ductile-to-brittle transition temperature of C-129 columbium has been determined to be below -320°F. Welding has been very successful with the welds withstanding a 1/2 t bend in the as-welded condition. Figure 3 is a photomicrograph of a C-129 weld. The success of this weld is the fact that the black spot, Yttrium oxide, holds the oxygen in solution. It can best be described as grease in water. The existence of Yttrium in columbium improves weld ductility because the Yttrium "grabs" all the oxygen and suspends it in the grain. Without Yttrium, the oxygen will go to the grain boundaries and result in poor ductility.

Wah Chang has been successful in rolling columbium into coils as opposed to previous methods of rolling each sheet to length. This, along with the other processing techniques, has increased the yield and lowered columbium prices considerably.

Tests have been completed and evaluated on the following weld combinations:

C-103 Cb to A-110AT Titanium

Temp, °F	Load, lb	Ultimate Strength, psi	Yield Strength 2% Offset psi	Elong, %	Location of Failure
RT	981	61,000		16.4	C-103 PM*
-320°	1745	109,000		14.6	C-103 PM
1800	65.5	5200		----	A110AT PM
RT	1034	64,000		13	C-103 PM
-320°	1790	112,000		12	C-103 PM
1800°	58	4600		----	A110AT PM

II, C, Nozzle (cont.)

Temp, °F	Load, lb	Ultimate Strength, psi	Yield Strength 2% Offset psi	Elong, %	Location of Failure
			C-103 to C-103		
RT		65,400	44,400	19	PM
-320°		122,000	101,300	15	PM
1800°		37,000	--	----	PM
			C-103 to C-129		
RT		58,500	43,300	9.3	Weld
-320°		120,000	103.5	4.2	Weld
1800°		37,800	--	----	Weld

*Parent Metal

IDENTIFICATION:	C-103	10 Hf	1 Ti	0.5 Zr
	C-129	10 Hf	10 W	
	A110AT	5 AL	2.5 Sn	

All columbium was coated with NAA 85 aluminide. Results are very encouraging as all columbium-titanium welds appear very sound, with failures occurring only in the parent metal. This weld combination resulted in good elongation properties. The C-103 to C-103 welds are very sound and, while the elongation is lower than usual, it appears that the extension meter gave a notch effect to the specimen. Theoretically, the specimens should not have any markings. The low elongation of the C-103 to C-129 was expected because of the tungsten content in the C-129 which causes interalloying and holds the oxygen in the grain boundaries. The addition of Yttrium appears to have eliminated this problem and improved results should be obtained during the next report period.

4. Coating

The vacuum retort for coating nozzle extensions is scheduled to be leak tested on 1 June. The unit will then be shipped to North American Aviation, Inc., Los Angeles Division, for a dry run of the diffusion coating process.

II, C, Nozzle (cont.)

Results of the titanium emissivity coating evaluation indicated that NAA S-31 has superior optical properties; and, of all the materials evaluated, there were only two coatings, NAA S-31 and one other, that did not deteriorate or change in structure. First run values on the NAA S-31 appear to be approximately 0.94. The other coating had a value of 0.85, but the vendor is no longer in business. The 0.94 value corresponds with the value of another testing source. This source is conducting extensive tests on both NAA S-31 and NAA 85. Typical values for NAA 85 are 0.91. Final results should be available during the next report period.

An attempt to locate a backup source for the diffusion coating has not been successful. The only coating vendor to respond is the Pfaudler Corporation, Rochester, New York.

The Pfaudler Corporation, whose product failed during the first coating evaluation, resubmitted a new coating, a desilicide process. While the final report on this coating is not complete, the following observations were made:

a. The coating greatly reduces the mechanical properties of the columbium.

b. The process seems to be very inconsistent, with certain areas of the columbium not being coated.

c. It is not possible to weld titanium to the coated columbium, a basic design requirement.

d. The coating is very coarse, and it would not be possible to seal the combustion gases at the chamber attachment point.

e. Money has been expended to build a vacuum retort that cannot be utilized with this process.

II, C, Nozzle (cont.)

f. This process has never been applied on any practical hardware, and the cost of the columbium nozzle does not allow for any unnecessary research and development.

g. The process apparently requires a long cycle-time-at-temperature because of the grain growth.

All these problems lead to the conclusion that the NAA process is the only one available that can meet the coating requirements of the Apollo service module engine nozzle extension. A secondary advantage is that during heat treating prior to coating, the NAA process effectively cures the welds of the nozzle extension and thereby eliminates an expensive heat-treat step which would ordinarily have to be done. A preliminary test was run on NAA 85 coated columbium at 3000°F. Results were satisfactory. This coating can withstand 3500°F if the processing is perfect. When accomplished, the substrait will be Cb_2 Al_5. As other columbium compounds are formed, the effectiveness of the coating is reduced.

Figure 4 is a 750X photomicrograph of a section of columbium fired at AEDC. The coating gave full protection to the columbium. Figure 5 is a photomicrograph of a columbium-titanium resistance seam-weld. Note the distinct interface between the two metals.

D. GIMBAL AND THRUST MOUNT

1. Design

The upgrading of all thrust mount and gimbal ring drawings has been completed.

Redesign of the injector actuator bracket is finished but awaiting completion of a stress analysis. The gimbal-ring weight reduction redesign effecting a material change from 0.20- to 0.150-in. thickness is completed.

II, D, Gimbal and Thrust Mount (cont.)

The bearing assembly weight reduction redesign has been initiated and is in process. Completion is scheduled for the end of May.

2. Fabrication

Fabrication of the six gimbal rings of the new design for the prequalification phase of the service module engine program is proceeding on schedule.

E. VALVES

1. Seals

a. Cage Seal

Detail drawings of the modified cage seal parts were completed and fabrication orders released. Incorporation of these new parts into top assembly drawings will be completed by 20 May.

On the basis of test and assembly experience, the existing cage seal has been modified by cutting back the outer seal leg. This will assure that maximum sealing force is applied at the inner seal leg where sealing must be effected. Future valves will be assembled with this cutback seal until the fully modified seal configuration is available.

During this period, endurance testing of the basic cage seal was limited. Approximately 5400 cycles have been run. At the last check (5000 cycles), GN_2 leakage was recorded on 3 of the 8 ball seals. Two upstream seals leaked 76 and 780 cc/hr at 240 psig respectively, and one downstream seal leaked 768 cc/hr at 240 psig. The other seals showed zero leakage at all test pressures from 2 to 240 psig.

II, E, Valves (cont.)

b. Bellows Loaded Seal

Detail drawings of the modified bellows loaded seal were completed and parts fabricated. Two sets of parts are being assembled. Testing will be conducted during the next report period.

2. Actuator

a. Piston

A preliminary layout, with a resized closing piston to balance opening and closing forces, has been completed. In conjunction with this piston redesign, inclusion of static seals for the closing piston has been accomplished. The piston diameter change is from 1.625 to 2.125 in. The static sealing is accomplished by the use of standard O-rings. Several methods of static seal retention are under consideration.

b. Actuator Force

First tests of a prototype valve, including a return spring in the actuator, show that the spring results in a slower opening and faster closing response than that previously obtained. A test series, including response-time tests and low-pressure functional tests, will be initiated 18 May. These tests are expected to provide confirmation of operation at minimum interface pressures.

c. Electrical

A proposal was completed and submitted to NAA on the revised electrical actuator concept. The concept submitted involves basically two flow control sections (one fuel and one oxidizer) with a gearbox between the sections.

II, E, Valves (cont.)

The sealed gearbox provides: (1) a mounting for four rotary electrical actuators; (2) contains the gears for desired speed reduction; and (3) contains the position indicating potentiometers. The proposal also included control systems for open- or closed-loop functioning of the actuators.

Effort is continuing on this approach in the areas of design criteria definition, analysis, and vendor liaison with respect to potential sub-components.

d. Four-way Valve Control

A review of proposals was completed. Subsequent analysis and discussion of the merits and costs of this approach in comparison to that of existing systems resulted in suspension of activity on the four-way concept. No further work on this concept is anticipated.

3. Pilot Valves

Test activity during this report period was concentrated primarily on the Schulz valves. Both the two-way and three-way valves satisfactorily completed an altitude test. Other component tests were directed toward isolation of potential trouble areas. Tests on the two-way valve revealed two areas for further investigation. One was uneven flow distribution from the two-way valve outlet. Another was increasing pressure drop as a result of filter clogging and collapse. These areas are being investigated to isolate causes and determine effects on main propellant valve performance. The only problem encountered with the three-way valve is a "chatter" condition experienced when the pilot valve dump lines are interconnected. Further testing and analysis is required to define the magnitude of this problem and whether it will be a factor during main propellant valve operation.

II, E, Valves (cont.)

Testing of other pilot valves was limited to analysis of failures during fluid-resistance tests. The cause of leakage in the Consolidated Controls valve was separation of main poppet seat seals from their normal seat location. The cause of leakage in the Hydraulic Research valve has not yet been satisfactorily determined, and further investigation will be conducted during the next report period.

F. GIMBAL ACTUATORS

1. Cadillac Gage Actuator Testing

During this period, Aerojet-General and NAA personnel conducted tests of gimbal actuators at the Cadillac Gage Company (CGC). Testing was performed to determine actuator transfer functions in order to redefine frequency- and step-response curve limits. The test data has been analyzed, and a special report is being prepared which covers these tests. Tests were completed on 7 May. A brief summary of the test data analysis is given below.

2. Tests

The frequency response tests were performed with a constant-voltage input sinewave-amplitude to give a 50 milliamp oscillation about a bias of 100 milliamps*. In the step-response test, the steady-state current was increased from 50 to 150 milliamps.

a. Current response to amplifier output voltage:

$$(I/V)(s) = \frac{Ki}{T_e s + 1}$$

Where: $6 < T_e < 8$ millisec

$$Ki = \frac{10^3}{64} \text{ milliamps per volt}$$

*A 50 ohm forcing resistance was used in series with the clutch coils.

II, F, Gimbal Actuators (cont.)

b. Clutch torque response to current:

$$(\tau/I)(s) = \frac{K_t\,(T_a s + 1)}{(T_1 s + 1)(T_2 s + 1)}$$

Where: $20 < T_1 < 33$ millisec

T_a is approximately $0.5T_1$, T_2 is approximately 1 millisec

K_t = 0.034 to 0.045 in-lb/milliamp

c. Force response to amplifier output voltage:

$$(F/V)(s) = \frac{K_i\,K_f\,(T_a s + 1)}{(T_e s + 1)(T_1 s + 1)(T_2 s + 1)(s^2/W^2 + 2\,ds/W + 1)}$$

Where:

d is less than 0.1

K_f = 3.10 to 3.95 lb/milliamp

W = 120 radians/sec, which is a function of the actuator spring mass system and the spring rate of the test fixture (primarily the test fixture load cell)

3. Test Analysis

The test data will match the transfer functions given above closely except:

a. In the torque-response-phase angle versus frequency curve, about 5° phase lag must be added to the theoretical curve.

b. In the force response of phase angle versus frequency curve, about 15° phase lag must be added to the theoretical curve.

c. About five millisec must be added to the theoretical force-to-voltage response curve.

II, F, Gimbal Actuators (cont.)

4. Reports

Replies to NAA SEM's 130 and 132 were transmitted on 18 April. It should be noted that the transfer functions given above are more correct than those given in the SEM answers.

Another special report, with recommendations for curve limits, will be published by the end of May. By this time Aerojet-General will have tested and analyzed data on three more CGC actuators and determined the necessary test equipment spring rates.

5. LSI Actuators

On 1 May, LSI actuator Model 3180E, SN XL03, failed during closed-loop testing. The failure area was the actuator snubbing casting. This was the same type actuator, tested under the same conditions, as the actuator that failed in March 1964 (see Aerojet-General Report 3865-01-20).

The Model 3180E, SN XL03 actuator was driving a load consisting of an interia load of 250 slug-ft^2 only. The actuator was inadvertently subjected to a hard oversignal that drove the load into the actuator snubbing stops. It was learned from Lear Seigler, Inc. (the manufacturer) that Models 3180E and 3180F (SN's XL01, XL02, and XL03) actuators have under-designed snubbing castings. The design of the castings was corrected to take specified snubbing loads by the addition of weld metal. This was done in Models 3180E-1 and 3180F-1 (SN XL04), Models 3180E and 3180F (SN XL04), and Models 3180G and 3180H.

Lear Seigler Models 3180E and 3180F (SN XL02) actuators were nearing completion of tests and were scheduled for use on engine assembly SN NF-1. Because of the snubbing casting failures of Models 3180E and 3180F (SN XL03), it has been decided to substitute Models 3180E and 3180F (SN XL03) for the failed actuator.

II, F, Gimbal Actuators (cont.)

A specific snubbing test was conducted on Model 3180H (SN XL05) on 7 and 8 May. The actuator successfully passed the ultimate loading of 250 slug-ft^2 plus a bias load of 300 ft-lb (simulated engine thrust misalignment) with a hard overstep signal to drive the load into the snubbing stops (-8.5° to +10.5° step). In the future, every actuator will be subjected to this snubbing test.

Closed-loop testing on the four sets of actuators that are to be delivered to NAA was completed on 4 May, and data reduction was completed on 6 May. Currently, the data is being prepared for transmittal to NAA for review before shipment of the actuators (as requested in NAA Ltr MA1-11-536). The disposition for these actuators follows:

LSI Model 3180 G and H, Serial No.	Usage
XL01	NAA development engine, SN 0000006
XL02	NAA development engine, SN 0000010
XL06	NAA nonfireable engine, SN 0000002 (NF-2)
XL07	NAA nonfireable engine, SN 0000001 (NF-1)

6. Actuator Clutch

On 25 April, while CGC was performing acceptance tests on actuator PN 085469-1, SN 0000003 (which was to be shipped to Aerojet-General on 28 April), a clutch failed in the actuator during frequency-response testing. This was the fourth clutch failure experienced out of 26 clutches received from Force Limited (FL), the manufacturer. Aerojet-General requested that CGC perform the equivalent stall-load of 300-lb actuator-output for 10 min, with the actuator at an ambient temperature of 140°F, in accordance with AGC Specification 11885B, Paragraph 3.4.17. All clutches subjected to this test failed with the actuator at room temperature. NAA and Aerojet-General engineering personnel conducted a design evaluation of the clutch at CGC on 11 May. This evaluation revealed that the materials used in the

II, F, Gimbal Actuators (cont.)

clutch were temperature-limited in that the coil wire was Form Var coated (insulation is good only to about 200°F); the epoxy potting compound was improperly cured; and the low temperature solder was used to connect the coil lead wires to the brush assembly. Work stoppages were issued at both FL and CGC until the clutch temperature problem could be corrected. The present problem solution program is:

a. To assemble clutches using ML polyamide coated wire (good to about 550° to 600°F) or ceramic coated wire if necessary.

b. Use epoxy potting compound which, with the proper curing procedure, is good to about 600°F; or use mineral-filled potting compound, if necessary.

c. Use 700°F solder or silver-soldered lead connections.

d. Use a high-temperature Viton seal in place of the Buna-N seal.

Testing is being conducted at both CGC and FL. It should be noted that these clutch failures are not catastrophic, because the actuator load can be switched to the standby channel. In all cases of clutch failure except one, the clutch became operable again after it cooled down. In the one failure exception, the clutch seized at high temperature because of the use of improper cure procedures for setting up the clutch coil potting compound. The present schedule of actuator deliveries is being delayed because of this clutch problem. Actuator delivery is dependent on the delivery of the special coated wire and the high-temperature Vitron seals. Furthermore, in changing the wire, the coating thickness will change. This creates another problem in that in order to obtain the required force gain, a considerable amount of investigation is needed to establish the proper ampere-turns, while still retaining the required coil resistance in accordance with the value indicated in the actuator specification.

II, Engineering (cont.)

G. PROPELLANT LINES

The qualification design of the propellant lines is complete, with all drawings having been upgraded to the Level 2.

H. ELECTRICAL HARNESS

Fabrication of the prequalification (prototype) harnesses is progressing satisfactorily. The first harness to be fabricated was diverted from the engine assembly schedule to the test schedule. Two additional harness sets have been fabricated, bringing the total to three sets during this report period.

Electrical harness testing at Space-General Corporation was halted for a three-week period following a failure of PN 090293 and PN 090294 harness assemblies. A substitute harness of the same part number failed to pass inspection and was returned to the vendor for evaluation and rework.

Electrical harness, PN 704997 and 705430, the prequalification configuration, is now being tested. The dielectric and insulation resistance tests have been completed successfully.

I. GROUND SUPPORT EQUIPMENT (GSE) AND SPECIAL TEST EQUIPMENT

1. <u>Ground Support Equipment (Deliverable)</u>

a. Sling

One sling assembly was shipped with engine assembly SN 0000006 to WSMR. Three sling assemblies are complete and acceptance tested. End item documentation is in process.

II, I, Ground Support Equipment (GSE) and Special Test Equipment (cont.)

b. Nozzle Closure

Five closures are complete and have been accepted. At NAA direction, these items are to be retained in a bonded storage area at Aerojet-General for shipment with engine assemblies.

c. Nozzle Extension Leak Check Test Set

The development test using a stubby nozzle extension was completed. There was no difficulty in maintaining pressure and no leakage to the ablative chamber past the special seal. NAA acceptance tests for two units are still required. The third unit is in fabrication.

d. Nozzle Plug

Seven units have been shipped. The eighth unit will be shipped on schedule. The pressure limitation of 105 psig on the engine assembly test is still valid. A design modification is in progress to eliminate the clamp ring and substitute two hold-down clamps to be attached to the gimbal ring. This change request will be submitted to NAA after analysis of the chamber failure report, if still required.

e. Nozzle Extension Protective Closure and Installation Kit

One kit assembly has been development tested with the nozzle extension scheduled for engine assembly SN NF-3. The skid and support assembly checkout was satisfactory, but the protective closure required rework to shorten the straps for tighter fit. This work is in process, and the first unit will be acceptance tested and shipped to NAA without a nozzle extension. Three units are complete in Azusa and will be used to ship completed nozzle extensions from Precision Sheet Metal to Sacramento for final fitup and test. Delivery of these units is dependent on the engine delivery schedule, because these items are shipping units for the nozzle extension.

II, I, Ground Support Equipment (GSE) and Special Test Equipment (cont.)

f. Nozzle Extension Closure

Three units are complete. The functional test requirement will delay shipment until a suitable nozzle extension is available to perform the tests.

g. Thrust Chamber Assembly Alignment Equipment

A complete set of jigs for the first unit are in receiving inspection. Initial inspection reports reflect several deviations. Final assembly has been delayed until disposition of parts can be completed. Two sets of telemicroscopes have been received and inspected.

h. Gimbal Actuator Locking Links

Four units at the vendor are held up pending release of the design change to prevent rotation and vibration of the locking links during shipping and firing. One unit will be fabricated on an expedited basis for use on engine assembly SN 0000010. A complete design layout is being prepared for the prequalification engine configuration for the last three units. This design will not have the capability of providing the actuator mechanical null but will be capable of securing the engine for test firing. The current stabilizer bars will be utilized for shipment of the engine. A change request will be processed for transmittal to NAA.

i. Low Pressure Plug

Fabrication of two items was initiated during this period.

j. Inertia Simulator

Fabrication of two items was initiated during this period.

II, I, Ground Support Equipment (GSE) and Special Test Equipment (cont.)

2. Special Test Equipment

a. General

All items of STE are complete or in final stages of fabrication. There are requests in process to NAA for several additional ground support equipment (GSE) and special test equipment (STE) items. These include a special nozzle plug to fit inside the thrust chamber assembly, special test equipment for radio frequency interference, and a cold gimbal fixture and a vibration fixture for the engine assembly. These items are urgently needed for completion of development and qualification tests required by contract.

b. Flow Calibration Unit

This item was successfully flow tested and proved capable of performing the required tests of the engine propellant system. A complete schedule of flow and balance tests is in process on engine hardware for engineering evaluation.

c. Moment of Inertia Simulator

This unit is still in fabrication. Final painting with special heat resistant paint is required for completion. This unit is required for gimbaling tests on deliverable and Sacramento development engines.

J. TESTING

1. Test Firing

During this report period, there were 78 firings conducted. Results are given below by test series.

II, J, Testing (cont.)

a. Pattern Performance Evaluation (c* Determination)

One injector (SN AFF-34, Pattern PONX-51-11) was fired for c* determination. Two firings were made, both resulting in immediate CSM shutdowns. Postfire hardware inspection did not reveal any damage to the injector.

b. Injector/Chamber Compatibility

There were no test firings conducted in this series during this report period.

c. Dynamically Stable Injector Pulse Tests

There were two pulse (bomb) tests conducted on injector SN 0000016 (6-4-2 type). The thermally ignited 156.9 grain charges were mounted approximately 6 in. below the center of the injector baffles. The peak pressure perturbation resulting from one bomb ignition was approximately 67 psi above the normal operating chamber pressure. During the second bomb test, heavy detonations occurred periodically throughout the run, resulting in pressure spikes as high as 80 psi. Stability recovery took place within 25 millisec.

Injector SN 0000009 (5-4-4 type) was also fired during this period. The test series consisted of three steel chamber firings followed by two 156.9 grain charge bomb tests for stability determination. Stability was recovered within 40 millisec; however, the exact recovery times (as well as pressure peak levels) are pending the completion of analysis of test results.

d. Dynamically Stable Injector/Chamber Compatibility Tests

Injector SN 0000016 (6-4-2 type) was test fired in a simulated mission duty cycle firing sequence. After the first firing sequence of 90.7, 17.6, 7.6, and 7.8 sec, the chamber (PN 177054-1, SN A-16) was examined and was in very good condition.

II, J, Testing (cont.)

During the scheduled 400 sec firing, numerous P_c perturbations occurred. The amplitude and frequency of these disturbances increased as the run progressed. After 334.5 sec of operation, the test was shut down because of the severity of these perturbations. Postfire inspection revealed chamber gouges adjacent to the injector baffle tips.

An intermanifold leak check performed on the injector revealed intermanifold leakage.

A series of seven ablative chamber/injector compatibility tests were conducted on injector SN 0000009 (5-4-4 type). There were no signs of excessive streaking, erosion, or gouging after a total of 752 sec.

e. Intermediate Frequency Investigation (600-cps)

Three injectors were test fired in this test series during this report period. Both steel and ablative chambers were used to try to determine the source of the 600-cps instability and then to effect its elimination.

Injector SN AFF-28 (pattern POUL 31-46) was test fired twice with a stell chamber. During both tests, moderate to heavy 600-cps oscillations occurred. Five additional tests were conducted using an ablative chamber (PN 177054-1, SN A-15). These tests included four 10-sec tests at nominal conditions (during which 600-cps was very evident) followed by a P_c survey in which P_c was gradually increased from 70 psia to 120 psia. Heavy 600-cps ($\pm$ 4 psi and above) occurred only in the region between 90 and 105 psia P_c. High frequency instrumentation traces were obtained on all runs and are currently being analyzed.

Injector SN AFF-29 was modified by the addition of flow separators in both propellant headers. The purpose of these flow separators was to prevent interaction of any flow disturbance taking place in the feed tubes.

II, J, Testing (cont.)

In addition, the 1-in. feed tubes were replaced with 3/4-in. lines. Moderate ($\pm$ 3-4 psi), 600-cps oscillations occurred on all four subsequent steel-chamber tests.

Injector SN AFF-32 (pattern POUL 31-43), as noted in the previous report, was equipped with Helmholtz resonators, which were to dampen the 600-cps phenomenon. Heavy 600-cps P_c oscillation occurred during the initial tests, one test being shut down because of a CSM-Gjy trip. A P_c survey was then made to determine the resonate frequency of the resonator. Four hundred cps was prevalent in the ranges below 80 psia P_c.

Both fuel and oxidizer feed tubes were stiffened by the addition of braces welded between the tubes and the pie-segmented sections. One resonator was removed at this time.

The next series of six firings were somewhat inconclusive as intermediate frequency oscillations occurred at random, with the resonator bleed open, and consistently with the bleed closed.

At this point a decision was made to conduct a series of firings with Monomethylhydrazine (MMH) replacing the AeroZINE 50 (A-50) as fuel. A pre-MMH series of five steel chamber firings was made with the resonator bleeds both open and closed for comparison with the intended MMH firings. Using A-50, these runs indicated $\pm$ 3 to 4 psi, almost continuously regardless of the bleed valve positioning.

The MMH-steel thrust chamber firings indicated less than $\pm$ 1 psi P_c fluctuation on all tests regardless of resonator bleed valve positioning. At the same nominal flow rates, the performance was almost identical with the A-50 tests.

II, J, Testing (cont.)

The steel chamber was replaced with ablative chamber PN 177054-1, SN A-3, and five firings were made totaling approximately 82 sec. P_c indicated very slight (less than 1 psi) 600-cps oscillations throughout the series.

The following is a data tabulation of the intermediate frequency test series, including injector SN AFF-32 firings with MMH and A-50 utilizing both steel and ablative chambers.

Run No.	Chamber PN, SN	Propellant	Duration, sec	Pc	$\dot{W}_t$	MR	Isp	C^*
131	177054-1 A-3	A-50	1.44	CSM-Gjy during start				
132	177054-1 A-3	A-50	2.57	101.2	71.46	1.995	192.5	5,536
133	177054-1 A-3	A-50	5.34	98.1	70.25	2.056	192.3	5,459
134	177054-1 A-3	A-50	10.67	99.6	70.32	2.098	190.8	5,525
135	177054-1 A-3	A-50	10.57	95.6	69.33	2.033	191.9	5,375
136	Steel	A-50	5.49	101.3	70.14	1.935	194.0	5,544
137	Steel	A-50	5.80	99.4	69.69	2.004	193.0	5,476
138	Steel	A-50	5.61	100.0	70.39	2.011	192.2	5,453
139	Steel	A-50	5.62	100.5	70.23	2.008	192.8	5,491
140	Steel	A-50	6.36	98.1	70.21	2.046	192.1	5,364
141	Steel	MMH	5.49	100.6	69.74	2.067	192.2	5,548
142	Steel	MMH	5.78	99.5	68.98	2.035	192.3	5,546
143	Steel	MMH	5.23	99.1	68.22	1.959	192.6	5,552
144	Steel	MMH	5.34	99.0	68.80	1.983	192.1	5,534
145	Steel	MMH	5.25	99.4	68.87	2.000	192.2	5,545
146	177054-1 A-3	MMH	10.65	98.4	68.47	1.969	191.7	5,629
147	177054-1 A-3	MMH	10.52	99.2	69.25	1.945	191.2	5,605
148	177054-1 A-3	MMH	10.40	99.8	69.52	1.983	191.8	5,614
149	177054-1 A-3	MMH	10.74	100.6	69.83	1.966	192.9	5,633
150	177054-1 A-3	MMH	30.89	100.7	70.10	1.988	192.6	5,629

II, J, Testing (cont.)

f. Prototype Determination

There were no tests conducted in this series during this report period.

g. Deliverable Engine Acceptance Tests

There were no tests conducted in this series during this report period.

h. Integrated Engine Components

Engine assembly SN 0000007 was test fired six times in this report period. The major components which made up the engine are:

Injector, SN AFF-54 (pattern POUL 31-10)
Chamber, PN 177163-1, SN 0000018 (cloth)
Valve, SN 0000021 (preprototype configuration)

The first firing, a 10.9 sec checkout-balance firing resulted in a 1.810 M.R. Postfire record inspection indicated that the inner flow circuit of the valve assembly failed to open (apparently because of a malfunction in the pilot valve assembly). The pilot valve operating the outer flow circuit malfunctioned and dumped fuel overboard throughout the firing.

The next test was an abbreviated simulated mission duty cycle sequence. The sequence consisted of 18.5, 8.2, 8.2, and 401.6 sec firings. Postfire second inspection indicated that the same pilot valve malfunctioned; however, the pilot valve that did operate did not leak or bypass fuel overboard during the firings.

The engine was removed from the stand, and both pilot valves were disassembled and thoroughly lubricated before the engine was reinstalled on the test stand.

During a subsequent functional test the valve failed to open completely. The pilot valve affected was disassembled and it was discovered that the piston sleeve had been inadvertently rotated 90°, thereby sealing off the actuator dump port. This situation was corrected and the engine was reinstalled on Test Stand C-11.

The final engine firing in the report period was a balance firing with approximately 40 sec of propellant in the tank system. This test was a "blowdown" test in which the propellant tank regulators were "locked off" or isolated from the system after initial pressurization. The purpose of the test was to determine if the slow response of the regulators was the cause of the mixture ratio excursions during previous runs. The results of the tests demonstrated conclusively that this was true because mixture was maintained successfully. In the future all acceptance tests will be conducted in this manner.

i. Deliverable Injector Acceptance Tests

Injector SN AFF-78 (pattern POUL 31-10) went through the deliverable injector firing sequence twice. The first firing sequence resulted in three gouges in the ablative chamber following the 30 sec compatibility firing.

The injector was returned to the hydrolab for pattern check before being returned to the test area for a repeat firing sequence. The repeat tests were meaningful, resulting in 96.5% of theoretical c* performance. The 30-sec ablative-chamber compatibility firing did not demonstrate any streaking or gouging tendencies.

j. AEDC Testing, Tullahoma, Tennessee

There were no tests conducted in this series during this report period.

II, J, Testing (cont.)

2. Component Testing

a. Evaluation Tests of Gimbal Bearing Assembly

Testing has been rescheduled to start in late May. Hardware is expected to be available during that period.

b. Electrical Harness Assembly

Harness assemblies SN-14 and SN-1 failed to meet specification requirements during the environmental test program. Excessive electrical leakage was noted during the initial dielectric test. Visual inspection of each harness revealed loose pins and uneven pin formations. A new set of harnesses, PN 704997 and PN 705430 (SN 0000007), was delivered to Space-General Corporation during the week of 4 May for testing. Results from testing the third set of harnesses have not yet been received.

c. Propellant Line Assembly

The reliability test program to evaluate the link-joints and bellows section of the propellant lines is continuing. A total of 16 sets of lines were submitted to cycling and flex tests until failure. Two sets have completed over 500,000 cycles with no failure indications. Each unit was pressurized to 165 $\pm$ 2 psig with water during the tests. The test conditions and test results are tabulated below.

II, J, Testing (cont.)

Unit	Size, in.	Angular Displacement, Degrees	Total Cycles	Remarks
1	3	± 8-1/2	40,837	Angulated with struts opposed 90° to plane of motion.
2	3	± 8-1/2	22,216	
3	3	± 8-1/2	30,347	Angulated with struts opposed 45° to plane of motion.
4	3	± 8-1/2	13,207	
5	2	± 8-1/2	27,630	90°
6	2	± 8-1/2	19,879	
7	2	± 8-1/2	54,230	45°
8	2	± 8-1/2	62,481	
9	2	± 3-1/2	1,000,000 (plus)	45°
10	2	± 3-1/2	716,000 (plus)	
11	3	± 3-1/2	1,000,000 (plus)	90°
12	3	± 3-1/2	500,000 (plus)	
13	2	± 3-1/2	200,000 (plus)	90°
14	2	± 3-1/2	200,000 (plus)	
15	3	± 3-1/2	200,000 (plus)	45°
16	3	± 3-1/2	200,000 (plus)	
17	2	3-1/2	46,501	Rotationally Angulated
18	2	3-1/2	32,278	
19	3	3-1/2	34,600	Rotationally Angulated
20	3	3-1/2	33,567	

Burst Pressure Tests

Unit	Size, in.	Burst Pressure, psi	Remarks
21	2	1900	New Bellows Section
22	2	1900	New Bellows Section
(10)	2	1900	Burst tested after 716,000 cycles
23	3	1650	New Section
24	3	1650	New Section
(12)	3	1100	Burst tested after 500,000 cycles

NOTE: Water pressure was 165 ± 2 psig during tests.

II, J, Testing (cont.)

d. Thrust Mount Assembly

(1) Static Structural Test

The static structural testing of the modified engine takeout struts is scheduled to start 29 June and to be completed 7 July.

(2) Vibration Testing

Test fixture design has been completed, and the design is being subjected to a stress analysis before final acceptance. Testing will start during the latter part of July and will be completed two weeks after start.

(3) Determination of Influence Coefficient

(a) Gimbal Ring Assembly

The revised test procedure to rerun these tests on the modified gimbal ring has been completed. Hardware is now expected to be available in early June. Testing will be conducted during the period of 22 to 29 July.

(b) Engine Thrust Mount Assembly

This test program, which will be conducted on the entire engine, is scheduled to be performed after completion of the vibration test program (Section II,J,2,d,(2)).

II, K, Special Studies (cont.)

d. Investigation of Intermediate Frequency Combustion Instability

Dynamics personnel are involved in two subtasks:

(1) The Design of Corrective Devices which will Eliminate the Intermediate Frequency Combustion Instability

A Helmholtz resonator has been designed and fabricated and is now being tested. The device is to be mounted on the fuel circuit only, because the initial stability analysis shows that the contribution of the oxidizer circuit to the instability is small. A report is being written which will explain the techniques used to design the acoustical filter.

(2) The Stability Analysis of the Engine-Feed System

An analytical model has been established which defines the closed-loop system that is involved in the intermediate frequency combustion instability. This model indicates the manner in which the feed system dynamics can cause instability and allows the stabilizing influence of corrective devices to be evaluated.

A digital computer program, which uses the equations defining the open-loop gain of the system, is now in operation to determine the stability of the system as a function of frequency.

e. Stability Analysis of the Engine-Actuator Assemblies

The analytical representation of the Cadillac Gage gimbal actuator assembly has been improved by the incorporation of experimental frequency response data. Separate response tests have been performed on both the magnetic clutches and the assembled actuator. The improved analytical response functions will now be used in future stability analysis of the engine-gimbal actuator assemblies.

II, Engineering (cont.)

K. SPECIAL STUDIES

1. Dynamics

Activity in both analytical and experimental dynamic investigations of the service module engine is given below:

a. Acquisition and Analysis of Vibration Data from Full-Scale Test Firings at AEDC

A complete analysis of the vibration data obtained from Test Firing J37B-03-01 has been completed. The data has been reduced by narrow band filters and a spectral analyzer to determine the acceleration amplitudes and frequencies during steady-state and transient engine operation. During the next report period, a report will be issued which describes the shock and vibration environment to which the engine is subjected during normal operation.

b. Analytical and Experimental Investigation of the Modes of Vibration of the Nozzle Extension Skirt

No work was performed in this area of analytical investigation during the report period.

c. Analytical and Experimental Investigation of the Modes of Vibration of the Thrust Chamber Assembly

A 6x6 matrix of flexibility influence coefficients has been computed by Aerojet-General structural analysis personnel. This matrix, which describes the flexibility characteristics of the thrust chamber support and gimbal structure, and the mass matrix, which describes the mass and inertia properties of the gimballed thrust chamber, are used as input to a computer program that will yield the natural frequencies of the six-degree-of-freedom thrust chamber. The rigid body dynamic characteristics will then be used to: (1) compare to the thrust vector control system characteristics; and (2) perform dynamic loads analyses.

II, K, Special Studies (cont.)

f. The Experimental Definition of the Fatigue Life of the Welded Titanium-Columbium Joint

The test program is continuing at General Dynamics Corporation, Pomona. The initial phase of the test program, where samples were tested at room temperature, has been completed. Testing at elevated temperature will begin during the next report period.

2. <u>Thermodynamics</u>

a. Engine Performance

Work is progressing on the study for the re-evaluation of performance of the service module engine nozzle extension. The final report is expected to be completed during the first week of June.

b. Nozzle Extension

Work was completed on the gas dynamic study to determine the contribution of the gas forces to the stiffness of the elastic nozzle extension gas flow system.

Two final heat transfer reports for the nozzle extension were published during the month. The first report was a thermal analysis of the Apollo service module engine nozzle extension skirt. The second was a supplement to this report.

These reports bring all heat transfer work on the nozzle extension up to date, and no further work has been initiated.

II, K, Special Studies (cont.)

c. Ablative Chamber

Work is proceeding on the effort to correlate the computer program results with available test results. A degree of correlation has been achieved. However, more test data are needed, particularly temperatures on the external wall. A report is being prepared to present accomplishments to date. When more test data are available, work will continue in order to complete the study.

d. Tullahoma Test Data Evaluation

Some work has been completed on the determination of significant thermal radiation view factors in the Tullahoma test cell. However, only a part of the task is now complete. As more information becomes available, it will be reported.

3. Structural Analysis

a. Injectors

The analysis of the 5-4-4 AVB-type injector for the component burst-test condition indicated minor structural deficiencies. These deficiencies have been corrected.

The structural analysis of the prequalification injector configuration (AFF-type) is continuing.

b. Propellant Lines

The detailed structural analysis of the fuel line (PN 091512) and the oxidizer line (PN 091513) has been completed, and results indicate the lines are structurally adequate.

II, K, Special Studies (cont.)

c. Bipropellant Valve

The results of the preliminary structural analysis of the prototype bipropellant valve indicate that several areas of the valve mechanism exhibit slight negative structural margins, while other areas could possibly be lightened if structural requirements are the limiting factors. The necessary design modifications are being incorporated to correct the deficiencies.

d. Ablative Thrust Chamber

The preliminary structural analysis of the 6:1 exit area ratio chamber has been completed for the component burst-test condition. The results of the analysis indicate that negative margins exist in the areas of the forward attachment flange and the throat adjacent to the gimbal support ring. The negative margins are a result of bending effect. Design modifications to correct the areas which were inadequate have been incorporated.

e. Nozzle Extension

The detailed structural analysis of the 40:1 columbium prequalification nozzle extension is progressing. The extension has been analyzed for boost loading conditions, gimballing loads, and shock loads. It is currently being checked for operating conditions at several intervals from ignition.

The effects of modification of the metallic seal used between the chamber and nozzle extension flanges are also being evaluated.

f. Gimbal Ring and Thrust Mounts

The preliminary analysis of the modified components comprising the thrust mount and gimbal ring was continued.

II, K, Special Studies (cont.)

The six-degree-of-freedom influence coefficient analysis is progressing. A rough order of magnitude analysis will be completed and forwarded to dynamics personnel for their use in conducting a general analysis. A more sophisticated approach will be used as soon as the computer program now under development is fully operational. The results of this analysis should enable a more accurate solution of the general dynamic characteristics of the structure.

g. Actuator Attachment Brackets

The preliminary structural analysis of the pitch actuator attachment bracket on the injector has been completed. The results of this analysis indicate that the bracket is satisfactory to withstand design loading conditions.

The use of the new pitch actuator attachment bracket (AGC Drawing 706127) imposes high localized bending stress on the injector and chamber. This bending stress is additive to the stress already present in the region caused by design operating loads. The superposition of stresses could result in negative margins when the final analysis of the components involved is completed. The analysis of this region is being completed on an expedited basis.

L. PERT

During this report period 78 schedule changes of the PERT rework were transmitted through the variance reports. Two logic changes were made to reflect the correct program restraints.

NAA requested that Aerojet-General transmit the monthly PERT variance TWX on Monday rather than Tuesday of the week that it falls due. Aerojet-General indicated that this would adversely affect the validity of the report because status information would then be based on the week prior to the week in which the report is due.

II, L, PERT (cont.)

A PERT network required to support the dynamically stable injector program was produced and published.

Layout of a new PERT network that deletes the completed events in the development phase of the program and includes logic revisions was begun. A preliminary copy was presented to NAA in a meeting at Aerojet-General, Sacramento, on 7 May, but it was the decision of NAA to adapt an "activity oriented" network as opposed to the event oriented network currently used. The following day was spent in conference with NAA, in which the details of the revision were discussed.

Incorporation of the revised program schedule into the new PERT network was initiated during this report period.

M. SYSTEM INTEGRATION

1. Development Engine Assemblies

a. AEDC (Simulated High Altitude Testing--Phase I)

Upon completion of Phase I of the Apollo service module engine high altitude test program at AEDC, engine assemblies SN 0000003, 0000004, and 0000008, were shipped to Sacramento. Further engineering evaluation of these engine assemblies and subassemblies is currently underway.

b. Sacramento (Sea Level Testing)

(1) Engine Assembly, SN 0000005

Currently, reassembly and subsequent testing of this engine is pending the reassignment of another bipropellant valve and injector to the engine.

II, M, System Integration (cont.)

(2) Engine Assembly, SN 0000007

During this report period, this engine, without gimbal actuators, was installed in Test Stand C-11, where balance test firings, followed by a mission duty cycle test firing, were conducted.

Actuation of the Futurecraft solenoid-operated pilot valves on the bipropellant valve assembly was not repeatable during these test firings as a result of improper lubrication of the O-rings on the sliding spool. A decision was made to remove the bipropellant valve assembly from the engine for necessary rework operations as follows:

(a) Incorporation of additional B-nut connections on the bipropellant valve to facilitate removal and installation of Futurecraft solenoid-operated pilot valves without having to cut welded lines.

(b) Disassembly and complete lubrication of existing Futurecraft solenoid-operated pilot valves used on bipropellant valve assemblies.

Reworked bipropellant valves will be used on engine assemblies SN 0000007 and 0000010 and subsequent engines. Other engine assemblies will be retrofitted with reworked bipropellant valves, as required.

(3) Engine Assembly, SN 0000009

This engine will be assembled for initial cell check-out test firings at AEDC during Phase II of the Apollo service module engine high altitude test program.

II, M, System Integration (cont.)

2. Deliverable Engine Assemblies

a. Engine Assembly, PN 090142-7, SN 0000006

During this report period, engine components containing "significant surfaces" (internal surfaces in contact with propellants, excluding the internal surfaces of the ablative thrust chamber) were cleaned in accordance with AGC Specification 46350, Level K. Other surfaces of these components were cleaned in accordance with Level H of this specification. Components that did not meet the required cleanliness levels were submitted to NAA as deviations.

After postfire component cleaning, the engine was reassembled and subsequently shipped to NAA, White Sands Missile Range, on 10 May.

b. Engine Assembly, PN 705989-9, SN 0000010

Reassignment of engine subassemblies to replace those damaged during the leak test failure of the engine thrust chamber assembly (Aerojet-General Report 3865-01-21, page 39) have been made as follows:

Part Name	Part No.	Serial No.
Injector	299526-3	AFF-78
Bipropellant Valve	085459-273	0000015
Thrust Chamber	704663-1	0000072

The bipropellant valve for this engine is currently undergoing solenoid-operated pilot valve rework operations.

II, M, System Integration (cont.)

3. Simulated Nonfirable Engine Assemblies

a. Engine Assembly, PN 08968-03, SN 0000002

Bipropellant valve assembly, PN 085459-267, SN CF-6 was shipped to NAA, Downey on 5 May, to complete all subassembly requirements for this engine.

b. Engine Assembly, SN 0000018

All assembly effort on this engine has been suspended as a result of the engine being rescheduled for delivery during the prequalification phase of the service module engine program.

III. WEIGHT AND BALANCE

Tables 3 and 4 present the current weight center of gravity, and inertia data for the service module engine. Table 3 has not changed during the current reporting period. Table 4 has been revised to correct errors in center-of-gravity and inertia values that were given in the last report.

Because the prequalification engine program is presently being redefined, additional weight savings will now be available for implementation into qualification engine hardware. These items are presently being evaluated and will be included in the next report.

Figure 6 is a sketch of the Apollo service module engine.

IV. MATERIAL

A. PROPELLANT LINES

Delivery of the first set of propellant lines of the new configuration maintains a first-week-in-June schedule.

B. NOZZLE EXTENSION

The order for seven nozzle extensions of the unstiffened configuration having columbium to the 40:1 section has been increased to nine. The first delivery is scheduled for mid-June.

C. ACTUATORS

One actuator was returned to the Cadillac Gage Company (CGC) for rework of the clutch.

During this period no actuators were received as a result of clutch, spring rate, and leakage problems (see Section II,F). The delivery schedule has been revised approximately three weeks, as given below:

Number of Actuators	Shipping Date
2	18 July 64
3	25 July 64
4	1 Aug 64
4	8 Aug 64
4	15 Aug 64

The delivery schedule for the remaining actuators is yet to be determined; however, an expedited delivery schedule is expected to make up for current delays.

V. MANUFACTURING

A. FABRICATION

1. Injectors, Dynamically Stable

Three injectors for the dynamically stable injector program were completed during this report period; one at Sacramento and two at Azusa. These injectors are currently being tested. The backup supply of AFF type injectors at the Azusa facility is being utilized on a need basis.

2. Gimbal and Thrust Mount

Design changes during this report period have imposed delays in the delivery schedule of this component. These design changes have been completed and have been released to the supplier. The change in delivery schedule will not exercise a restraining effect upon engine buildup.

3. Valves

The first prototype valve, SN 0000030, was completed during this report period. The schedule of deliveries for the prototype valve is set at one per week beginning in late June. This delay is caused by fuel valve body fabrication problems. Delays in receipt of pilot valves will be the pacing item after the next five valves are assembled.

Several errors have been found in the tooling and numerical control machine used in valve manufacture which are believed to be the basic cause for dimensional discrepancies in fuel valve bodies. Corrections to the tooling and numerical control machine will be completed by the 25th of May, and fabrication of fuel valve housings will then continue.

V, A, Fabrication (cont.)

4. Chambers

During this reporting period, fabrication orders for new design chambers have been released. The new design will solve proof-pressure testing problems.

B. TOOLING

1. Engine Assemblies

Three tools for engine assembly were ordered and received during the report period.

2. Thrust Chambers

One tool for use in chamber fabrication was ordered and received during the report period.

3. Injectors

One tool for injector fabrication was ordered during this period, and delivery is to be made during the next report period. The anticipated delivery date is 20 May.

4. Valves

Three tools for use in bipropellant valve assembly have been ordered. All are expected to be delivered prior to need dates.

C. FACILITIES

Cleanliness facilities for the Apollo program are nearing completion. The clean room for engine assembly is operational, and the tent for component cleaning has been installed and will become operational during the next report period.

VI. QUALITY ASSURANCE

A. SUPPLIER QUALITY CONTROL

Action is currently being taken to include NPC 200-2 in the Cadillac Gage Company contract for actuators.

B. INSPECTION PLANNING

1. Engines

Engine Assembly SN 0000006 was delivered during the reporting period. Review of records with North American Aviation brought to light a lack of clear definition of the contents of the end item report. In order to obviate the difficulties which arose on engine assembly SN 0000006 in the future, it is essential that North American Aviation and Aerojet-General discuss and reach agreement on the specific contents of the end item report.

Injector SN AFF 78, assigned to engine assembly SN 0000010, underwent acceptance testing. Initial tests on this injector indicated some streaking of the chamber and resulted in modification of the injector hole pattern. Criteria for allowable streaking has not been determined. In order to permit objective quality control of injector testing, it is necessary that such criteria be established.

2. Quality Control Program Plan

NAA comments on the Quality Control Plan, Aerojet-General Report 3865-9B, 17 October 1963, were received in January 1964. Exception to three comments was taken by Aerojet-General and mailed to NAA on 3 February 1964.

VI, B, Inspection Planning (cont.)

3. Special Gaging for Inspecting Bipropellant Valves

A number of special gages has been requested for the inspection of the machined fuel and oxidizer valve bodies of the bipropellant valve. To date, only a portion of these gages have been approved for procurement. Dimensions to be inspected by the remaining gages cannot be inspected by means of standard measuring instruments. Efforts have been made to inspect the fuel body using a jig bore. This has been partially successful; however, three dimensions cannot be inspected and the use of the jig bore will result in costs far exceeding the estimated cost of the requested gaging.

4. Ablative Thrust Chamber Failure

During the last reporting period, a failure was reported on the ablative thrust chamber wherein the forward flange separated from the chamber. Corrective actions that have been taken to prevent recurrence of this failure are given below.

The outer flange surfaces will be cleaned, using an acid etch-paste solution in place of the solvent cleaning process. A water-break test will be performed to ensure a satisfactory bonding surface. Inspection surveillance will be performed throughout the complete operation.

Continuous laminants of glass cloth will be applied under and over the forward flange. The thickness of each laminant will be capable of withstanding the entire load applied under the most severe pressure conditions. The previous design allowed the glass laminant under the flange to terminate approximately 2 in. beyond the aft end of the flange.

VI, Quality Assurance (cont.)

C. QUALITY CONTROL DESIGN REVIEW

During the reporting period, quality engineering reviewed the following:

Engineering Drawings	139
Drawing Changes	125
Engineering Change Requests	11
Engine Test Directives	21
AGC Specifications	9
Welding and Nondestructive Test Procedures	9

D. INSPECTION RESULTS

During the reporting period, the following inspection results were obtained in in-plant and receiving inspection.

	In-Plant	Receiving Inspection
Parts Inspected	567	16,616
Parts Discrepant	67	730
Characteristics Discrepant	358	1,225
Percent Discrepant	11.8%	4.4%

VII. RELIABILITY

A. PROGRAM ADMINISTRATION

The April monthly reliability surveillance meeting with North American Aviation, Inc., S&ID representatives, was held on 16 and 17 April 1964. Minor changes in the physical presentation of the reliability estimates and the frequency of analyses were discussed. Failure analysis format, component safety margins, VII, A, Program Administration (cont.)

changes in the reliability program plan, and the reliability program for vendors were also covered. It was agreed that the reliability requirements in the component specifications should be more definitive. The rewritten sections of the various component specification reliability requirements are essentially complete and have been submitted to cognizant personnel for incorporation into the basic specification.

Correction and deletion sheets for the reliability program plan have been transmitted to NAA/S&ID. After concurrence by NAA/S&ID, the reliability program plan will be published and will be available for general distribution.

The majority of the prequalification design review action items have been answered and transmitted to NAA/S&ID. It is anticipated that the remaining action items will be answered in the next reporting period.

B. RELIABILITY ANALYSES

During the monthly reliability surveillance meeting, NAA/S&ID requested that Aerojet-General prepare monthly reliability estimates of the specific component designs and engine configurations if the data were sufficient. However, in monitoring the data for a one month period, it has been determined that the data are insufficient. Therefore, Aerojet-General feels that estimates should be made on a quarterly basis. The sequential plot of engine hot firings has been reoriented: Failures versus trials axes have been switched. It was also requested that reliability estimates of the service module engine, based on the elimination of failures for which design fixes have been achieved, as well as reliability estimates of start, steady-state, and shutdown capabilities be generated. These estimates have been completed and will be upgraded and included in the next quarterly report with the reoriented plot, the reliability growth curve, reliability estimates of particular component designs, and changes in the functional logic diagrams, failure mode and effects analyses, and the assumptions and restrictions.

VII, Reliability (cont.)

C. FAILURE REPORT AND ANALYSIS

1. Failure Reports

A summary of the reportable failures occurring during this report period is presented in Table 5. Copies of forms reporting these failures have been forwarded to NAA.

2. Failure Analysis Reports

The following is a summary of the failure analysis reports that were issued during this period.

a. Failure Analysis 58 (F.R. 229)

The first configuration of Engine Assembly SN 0000006 failed to meet specification requirements for a number of performance parameters. The engine was reworked, and component development work is continuing in an effort to meet these requirements on future engines.

b. Failure Analysis 59 (F.R. 230)

The first test of injector PN 090827-7, SN BF-16, (pattern POUL 41-16) was a stable, successful firing of a nominal 5 sec duration. Posttest inspection revealed hub and baffle damage and a crack in an oxidizer tube-to-pie section weld. The hub damage was caused by spurious oxidizer streams, and the baffle damage by a weld around a support pin cracking out. The tube-to-pie-section crack was the result of an inadequate weld and a highly stressed joint design. The support pin and tube-to-pie-section joint designs have been changed and the pattern will be modified prior to further testing.

VII, C, Failure Report and Analysis (cont.)

c. Failure Analysis 63 (F.R. 239)

Bipropellant valve SN CF-5 failed to close on shutdown signal at the conclusion of an AEDC test. The valve was returned to Sacramento where it was disassembled and analyzed for cause of failure. The workhorse pilot valve and the cam, roller, gear, and rack mechanism were determined to be the source of failure. Corrective action consists of reworking the pilot valve and the use of revised assembly techniques when adjusting the cam, rack, and gear mechanism.

d. Failure Analysis 64 (F.R. 240)

During the cleaning and reassembly of Engine Assembly SN 0000006 (first configuration) following acceptance tests, the injector (PN 299526, SN AFF-16) was found to have a small crack in a face ring braze joint. A simulated mission duty cycle firing caused only slight propagation of the crack and did not affect injector performance. There are no plans presently to fabricate additional brazed face ring injectors. Electron beam welding is being used for injectors of the dynamically stable injector program.

e. Failure Analysis 66 (F.R. 242)

Injector PN 299525-5, SN AFF-58 (pattern POUL 31-10), was fired with ablative chamber PN 704664-1, SN 0000016, for a simulated mission duty cycle. The test was terminated prematurely at 561 sec when the chamber burned through. A review of pattern POUL 31-10 ablative firings revealed a significant injector-to-injector variability in chamber-gouging characteristics, which can be determined only by firing each injector with an ablative chamber and then inspecting the chamber.

VII, C, Failure Report and Analysis (cont.)

f. Failure Analysis 73 (F.R. 251)

After three firings of Engine Assembly SN 0000007, totaling 83 sec, a visual inspection revealed two cracks at the base of one thrust takeout strut, PN 091047-1, SN A-44. The failure was attributed to lack of sufficient material ductility and to excessive stresses induced during fabrication. The heat-treating requirement has been changed to increase ductility, and the riveting procedure has been changed to reduce fabrication stresses.

g. Failure Analysis 74 (F.R. 252)

The final configuration of Engine Assembly SN 0000006 failed to meet specification requirements for several performance parameters. Component development work is continuing in an effort to improve engine performance in these particular areas.

h. Failure Analysis 75 (F.R. 253)

Bipropellant valve PN 085459-267, SN 0000016, used on the final configuration of Engine Assembly SN 0000006, had ball seal and actuator leakage in excess of specification requirements after engine acceptance testing and decontamination. The valve also had a cracked weld on a bleed line fitting. The use of omniseals in the valve has proved unsatisfactory, and they are being replaced by O-rings. Ball seal development is still in process to identify and eliminate sources of ball seal leakage; the drain and bleed line attachment design will be changed to eliminate the welded fitting.

i. Failure Analysis 77 (F.R. 256)

During a post-acceptance-test leak check, Engine Assembly SN 0000006 exhibited GN_2 leakage in the chamber/injector flange areas and at the

VII, C, Failure Report and Analysis (cont.)

chamber-positioning bracket, mounting-ring bolt holes. The chamber design has been changed to extend the rubber sheath under the forward flange continuous-ring and to double the thickness under the support ring.

j. Failure Analysis 78 (F.R. 257)

Failures of position-indicating potentiometers were experienced during various functional tests of Engine Assembly SN 0000006 bipropellant valve. Investigation of the more recent failures has disclosed two primary causes of failure: internal corrosion and broken internal wires. Several design changes have been made, and a new supplier has been selected, but additional analysis may require further changes.

k. Failure Analysis 79 (F.R. 259)

Engine Assembly SN 0000006 did not meet the specification requirements for cleanliness. Facilities capable of producing the required degree of cleaning will be available for use on the next deliverable engine.

VIII. SUPPORT

A. TECHNICAL SERVICES

1. Field Support

a. General

Aerojet-General field support personnel are continuing coordination and technical assistance at the White Sands Missile Range propulsion systems development facility, with NASA and NAA S&ID personnel.

VIII, A, Technical Services (cont.)

b. Engine Assembly SN 0000006

Apollo service module engine assembly SN 0000006 was received at PSDF/WSMR on 12 May 1964. The engine underwent receiving inspection by NAA and NASA quality control personnel, with AGC assistance.

The inspection of the engine and log book resulted in minor "carb" writeups, such as lack of flow indicators on the major propellant lines, the fuel and oxidizer orifice sizes not being indicated in the log book, and the thrust chamber throat measurements taken after the last firing also not being covered in the log book. Action has been taken to correct these deficiencies.

It is reported that NAA-Test Operations has commenced installation of the transducers on the engine, and engine leak and functional checks are scheduled to begin by 18 May.

2. Engine Test Directives (ETD's)

The following is the Apollo ETD status:

a. Forty-two of the scheduled 47 engine ETD's have been submitted to NAA-S&ID with the required quantity of copies and reproducibles.

b. Of the remaining 5 ETD's, one has been released, one is in preliminary form for engineering review, and three are awaiting engineering information.

c. A total of 35 ETD revisions have thus far been requested, with 28 of these released and submitted. The remainder are being published.

VIII, A, Technical Services (cont.)

3. Technical Manual

There is no change on the Engine Maintenance Manual, SMA5-801, which is still undergoing NAA/S&ID review.

Proposal LR642004, follow-on effort for updating and maintenance of the SPS engine manual, is also undergoing NAA/S&ID review.

4. Provisioning Parts Breakdown (PPB)

The following is the status of the PPB's for this report period:

a. Revision 2 to Increment XIV of the PPB's for the Apollo service module engine is being reproduced and will be submitted to NAA by the end of May.

b. Increments V, VI, and VII of the provisioning parts breakdown for Apollo AGE were submitted on 24 April.

c. In accordance with NAA Documentation Specification MC999-0025A, Paragraph 3.9.4; a new provisioning parts breakdown is presently being prepared for submittal in June 1964.

d. Revision 1 to Increments I, II, III, IV, V, VI, and VII of the Aerospace Ground Equipment Provisioning Parts Breakdown is being prepared for submittal in June.

VIII, Support (cont.)

B. SPECIFICATIONS

The following new specifications, revisions, and amendments were released during this report period:

AGC Number	Title
10189 Amend-2	Container, Storage, Shipping, Handling, Reusable, AJ10-137, Rocket Engine
14091A Amend-1	Electromagnetic Interference Control for Aerojet-General Aerospace System Rocket Engine AJ10-137
46598 Rev. A	Injector Assembly for AJ10-137 Rocket Engine, Acceptance Test Firing For
46605 Rev. B	Sling, Rocket Engine Handling, Acceptance Test For
46652	Cleanliness Requirements for the Apollo Service Module Engine
46656	Nozzle Extension, AJ10-137 (Apollo) Rocket Engine, Acceptance Test For
46659	Nozzle, Columbium Alloy, AJ10-137 (Apollo), Heat Treatment of
46660	Rocket Engine Assembly AJ10-137 (Apollo), Preparation for Delivery

TABLE 1

THRUST CHAMBER RADIAL DEFLECTION, PN 704663-1, SN 044

Pressure Condition		DEFLECTION IN INCHES x 10^3											
		DIAL INDICATOR LOCATION											
		1	2	3	4*	5*	6	7	8	9	10	11	12
0 psig	Before Test	0	0	0	0	0	0	0	0	0	0	0	0
0 psig	Before Test	0	0	0	0	0	0	0	0	0	0	0	0
25 psig	Exercise	-	-	-	-	-	-	-	-	-	-	-	-
25 psig	Test	0	0	0	0	0	.25	.25	.60	.25	1.30	2.00	1.10
15 psig	Return	0	.20	0	0	0	.25	.25	.60	.25	1.00	1.30	.60
50 psig	Test	0	.10	.25	.50	1.00	.40	.50	.80	.75	1.60	2.50	1.35
15 psig	Return	0	.50	.50	.75	1.00	.30	.25	.45	.75	.50	.50	.40
75 psig	Test	.40	.20	.50	1.00	1.00	.50	1.00	1.40	1.50	3.00	4.50	2.80
15 psig	Return	.40	.20	.40	1.00	1.00	0	.15	.25	1.75	.40	.50	.30
100 psig	Test	.25	0	.25	1.00	1.00	.75	1.40	2.00	2.50	4.35	7.00	4.20
15 psig	Return	.25	0	.25	1.00	1.00	0	0	.10	2.50	.40	.65	.40
125 psig	Test	.25	-.15	.40	1.50	1.00	1.20	2.00	3.00	3.75	6.00	9.80	5.70
15 psig	Return	.25	0	.25	1.50	1.00	0	.20	.25	2.50	.50	1.00	.60
150 psig	Test	.25	0	.70	2.00	1.00	1.90	3.00	4.30	5.00	7.80	13.00	7.50
15 psig	Return	.40	.20	.50	2.00	1.20	.10	.30	.30	2.80	.60	1.50	.90
175 psig	Test	.40	0	1.00	2.10	1.30	2.50	3.75	5.50	6.50	9.50	15.90	9.20
15 psig	Return	.50	.40	.60	2.00	1.50	.30	.50	.50	2.00	.80	1.90	1.20
200 psig	Test	.50	.10	1.25	2.40	1.50	3.10	4.55	6.70	7.70	11.40	19.00	11.50
15 psig	Return	.50	.40	.60	2.00	1.65	.40	.50	.50	2.50	1.00	2.20	1.50
225 psig	Test	.50	.10	1.40	3.00	1.20	3.60	5.50	7.75	9.10	13.40	22.30	13.50
15 psig	Return	.60	.40	.60	2.20	1.75	.40	.60	.50	2.60	1.00	2.50	1.50
250 psig	Test	.60	.10	1.60	3.00	1.20	4.40	6.40	9.00	10.50	15.30	25.20	15.70
15 psig	Return	.80	.50	.60	2.50	2.00	.50	.75	.70	2.60	1.20	3.00	1.90
275 psig	Test	.60	0	1.75	3.20	1.00	4.80	7.20	10.10	12.00	17.10	28.50	17.80
15 psig	Return	.90	.50	.60	3.00	2.00	.40	.65	.65	2.55	1.30	3.20	2.00
280 psig	Test	.80	.10	1.80	3.50	1.20	5.00	7.50	10.60	12.60	18.00	30.40	19.00
15 psig	Test	1.00	.50	.60	3.00	2.00	.50	.75	.70	2.60	1.40	3.50	2.25

*NOTE: All deflection values in columns 4 and 5 are negative.

TABLE 2

APOLLO AFF INJECTOR, 600 CPS PROGRAM

15 May 1964

AFF-27

OBJECTIVE: To determine resonant frequencies of injector and analyze for possible coupling with combustion process.

RESULTS: Vibration Tests complete 2-24-64.

1. 635 cps resonance of fuel tube
2. 1600 cps resonance of dome
3. No conclusive results

OBJECTIVE: To dampen 600 cps oscillations using tuned organ pipe type dampeners in injector manifolds.

RESULTS: Test series completed with intermittant pressure oscillations varying in intensity. There is some evidence of attenuation due to the resonators, but the short duration of the tests limits analysis.

OBJECTIVE: To test fire an ablative chamber and vary chamber pressure to determine the effective range of the dampeners.

RESULTS: The resonators were effective when the combustion frequency fell into the band covered by all resonators. Effectivity varied with the number of resonators. There are indications that the dominant oxidizer circuit frequency is 400 cps; the fuel circuit 600 cps.

OBJECTIVE: To return the injector to its original configuration and pattern POUL 31-37 for test with prototype resonator assembly.

RESULTS: Injector is drilled to POUL 31-37 and waiting for resonator. Resonator is being modified for dynamic tuning.

AFF-34

OBJECTIVE: To further evaluate Quad-let Pattern POMX 51-11 with which AFF-4 had no indication of 600 cps oscillations.

RESULTS: Pressure pickup boss failed on 1st test. Two subsequent tests resulted in CSM shutdowns.

AFF-28

OBJECTIVE: Modify oxidizer header deflectors to equalize pressure in distribution pies and to eliminate possible cavitation.

RESULTS: Firings completed 2-24-64.

1. Modification failed to eliminate 600 cps oscillations.

OBJECTIVE: To eliminate possible hot areas in outer fuel channel by the addition of six .030 diameter bleed orifices opposite each oxidizer pie segment. Pattern designated POUL 31-41.

RESULTS: Firings completed 3-4-64.

1. Modification failed to eliminate 600 cps oscillations.

OBJECTIVE: To investigate the effect on combustion process by changing film coolant from swirl to straight. Pattern designated POUL 31-42.

RESULTS: 3 steel T.C. tests were made with indications of reduced amplitude in the 600 cps oscillations. A mission duty cycle with a 1.5:1 ablative thrust chamber was terminated after 117 sec and 5 starts due to Hi frequency.

OBJECTIVE: To modify the film coolant with orifices of alternate diameters to investigate the apparent trend noted with POUL 31-37 in injector AFF-32. This POUL 31-46.

RESULTS: Modification did not eliminate 600 cps oscillations.

OBJECTIVE: To modify the pattern to POUL 31-47 by eliminating orifice elements and determine the effect of a 60 psi ΔP.

RESULTS: Injector was test fired in a series of ablative tests. Preliminary data showed oscillations at low Pc which disappeared in the 100 psia region.

AFF-29

OBJECTIVE: To reduce the fuel injection pressure drop from 40 to 22 psi and determine the effects on performance and the combustion process. Pattern designated POUL 31-40.

RESULTS: Tests completed on 3-3-64.

1. The reduced fuel pressure drop did not eliminate the 600 cps oscillations.

OBJECTIVE: 1. To evaluate the nozzle structural effects on the injector by changing from a conical to a contoured exit nozzle.

2. To brace fuel tubes and eliminate possible coupling effects on 635 cps noted with AFF-27.

3. To investigate possible effects of dome deflection by strengthening with preloaded beam.

RESULTS: The modifications did not eliminate the 600 cps oscillations.

OBJECTIVE: To investigate the combustion effects of eliminating the film coolant. Pattern designated POUL 31-44.

RESULTS: Three C* tests were conducted. All had severe 600 cps oscillations.

OBJECTIVE: To weld separators in both fuel and oxidizer headers to prevent interaction of any flow disturbances in the tube systems and to decrease fuel inlet tubes to 3/4" dia and investigate trend noted with single fuel tube in AFF-32.

RESULTS: Modification did not eliminate the 600 cps oscillations.

AFF-63

OBJECTIVE: To determine resonant frequencies and possible coupling with the combustion process of a pressurized and fluid filled injector. Pattern is not drilled.

RESULTS: Received Air Force approval for use of vibration shaker. Testing is now in process. Preliminary result indicates bracing of fuel tubes eliminating severe 580 cps oscillations obtained while vibrating with fluid.

AFF-32

OBJECTIVE: To vibrate and test fire a TCA to determine vibration frequencies of the complete installation.

RESULTS: Tests completed 2-22-64.

1. Analysis fails to indicate that coupling frequencies exist in the system.

OBJECTIVE: To modify the pattern to POUL 31-37 for configuration of the smooth results previously obtained with injector AFF-61.

RESULTS: Tests completed 3-7-64.

1. The modification decreases the incidence and magnitude of the 600 cps oscillations.

OBJECTIVE: To increase the film coolant and investigate the apparent trend noted with POUL 31-37. Pattern is designated POUL 31-43.

RESULTS: One 200 sec and five 10 sec tests conducted in a 1.5:1 ablative thrust chamber. Slight and intermittent 600 cps. Excellent compatibility.

OBJECTIVE: To evaluate the structural nozzle effects on the injector by use of a 6:1 ablative thrust chamber.

RESULTS: One 200 sec and five 10 sec tests did not reduce the 600 cps from the amplitude noted in the previous test series. Excellent compatibility.

OBJECTIVE: To confirm the results obtained in the previous tests.

RESULTS: Mission Duty Cycle was terminated after 486 sec and six starts due to abrupt drop in Pc.

OBJECTIVE: To simulate increased fuel flow in channels of AF type injectors by eliminating one fuel tube.

RESULTS: Test series completed with no indications of 600 cps oscillations.

AFF-32

OBJECTIVE: To test the suppression ability of a Helmholtz resonator designed from data obtained testing AFF-27 with dampeners.

RESULTS: Two 5 sec checkout tests had severe 600 cps oscillations. Doublers were added to stiffen the resonators and 220 sec test was conducted from 75 psia to 120 psia. There was smooth operation in the range of 85 to 120 psia. There were 400 cps oscillations below 85 psia. There were no 600 cycle oscillations.

OBJECTIVE: To detune the resonators and add fuel tube braces to investigate the results of testing with AFF-63.

RESULTS: Modification did not eliminate the 600 cps oscillations.

OBJECTIVE: To test with MMH to examine the effect of an alternate fuel on the 600 cps oscillations.

RESULTS: The injector is currently being fired. Only low amplitude 600 cps present.

OBJECTIVE: To remove one Helmholtz resonator and make provisions to tune and detune the remaining resonator during test and verify suppression ability.

RESULTS:

TABLE 3

CURRENT WEIGHT STATUS

	WEIGHT AND BALANCE STATUS											
	APOLLO S.M. ROCKET ENGINE Model AJ 10-137 Contract P.O. M3J7XA-406014 Issue Date 15 April 1964	Original Weight as of AGC 10141 Dated	Approved Changes	Spec. Max Revised Weight 2 + 3 (Target)	Contractor +Over - Under Spec Weight	Current Status 4 + 5 or 7 + 8	Last Status Issue No.___ Dated 15 Mar. 1964	Change Between Last & Current Status Reports: Contractor Changes	Basis for Current Data: Per Cent Est	Basis for Current Data: Per Cent Cal	Basis for Current Data: Per Cent Act	Noted on Page 2
	1	2	3	4	5	6	7	8	9	10	11	12
1	Thrust Chamber	-		(354.0)		(382.1)	(383.0)					
2	Injector	35.0	+3.0	38.0	+1.2	39.2	43.0	-3.8			100	(1)
3	Combustion Chamber	184.7	-2.7	182.0	+14.9	196.9	194.0	+2.9			100	(2)
4	Nozzle Extension	56.0	+78.0	134.0	+12.0	146.0	146.0			100		
5	Thrust Structure	-		(95.0)		(95.3)	(98.0)					
6	Ring & Gimbal Bearings	47.2	+37.8	85.0	+4.0	89.0	88.0	+1.0			100	(3)
7	Thrust Struts	-	+10.0	10.0	-3.7	6.3	10.0	-3.7			100	(4)
8	Controls & Valves	-		(85.0)		(105.4)	(122.3)					
9	Main Valves	59.0	+1.0	60.0	+21.3	81.3	97.3	-16.0		10	90	(5)
10	Check Valves	-		-								
11	Electrical Harness	-	+25.0	25.0	-.9	24.1	25.0	-0.9			100	(6)
12	Propellant Lines	-		(37.0)		(34.9)	(34.0)					
13	Main Lines	-	+29.0	29.0	-1.0	28.0	26.5	+1.5			100	(7)
14	Valve Act. Dump Line	-	+3.0	3.0	-0.7	2.3	2.9	-0.6			100	(8)
15	Drain & Bleed Lines	-	+3.0	3.0	-0.3	2.7	2.7			100		
16	Screens,Orifices,Brackets	-	+2.0	2.0	-0.1	1.9	1.9			100		
17	Thrust Vector Controls	-		(52.0)		(57.4)	(52.0)					
18	Pitch Actuator	-	+26.0	26.0	+2.7	28.7	26.0	+2.7		100		(9)
19	Yaw Actuator	-	+26.0	26.0	+2.7	28.7	26.0	+2.7		100		(10)
20	Attaching Hardware	5.0	+2.0	7.0	-7.0	0.	7.0	-7.0				(11)
21	Subtotal: (dry)	386.9	+243.1	630.0	+45.1	675.1	696.3	-21.2				
22	Check Valve	-	+2.0	2.0		2.0	2.0					
23	Contingency	-	+10.0	10.0		10.0	10.0					
24												
25	Total: (dry)			642.0	+45.1	687.1	708.3	-21.2				

TABLE 3 (cont.)

WEIGHT CHANGE RECORD - WEIGHT AND BALANCE STATUS					
APOLLO SERVICE MODULE ROCKET ENGINE MODEL AJ 10-137 CONTRACT P.O. M3J7XA-406014 ISSUE Date 15 April 1964					
		(Noted)	GOVT WEIGHT CHANGE	CON-TRACTOR WEIGHT CHANGE	REMARKS
1	Injector	(1)		-3.8	Weight reduction due to reduced flange
2					thickness , -4.9. Addition of attach. parts +1.6
3	Combustion Chamber	(2)		+2.9	Addition of attaching parts
4	Ring & Gimbal Bearings	(3)		+1.0	Actual weight of ring and bearings
5	Thrust Struts	(4)		-3.7	Weight reduction due to redesign and
6					material changes
7	Main Valves	(5)		-16.0	Incorporation of hollow balls and aluminum
8					cages
9	Electrical Harness	(6)		-0.9	Actual weight of harness
10	Main Lines	(7)		+1.5	Addition of attaching parts
11	Valve Actuator Dump Line	(8)		-0.6	Actual weight of line
12	Pitch Actuator	(9)		+2.7	Weight quoted by supplier
13					(also includes 0.5 lb attaching parts)
14	Yaw Actuator	(10)		+2.7	Same as above
15	Attaching Hardware	(11)		-7.0	Transferred to items attached

TABLE 4

CENTER-OF-GRAVITY AND INERTIA DATA

APOLLO SERVICE MODULE ROCKET ENGINE

DATE: 15 May 1964 Item		Weight	Centers of Gravity x	y	z	Inertias I_{ox}	I_{oy}	I_{oz}
1	Thrust Chamber							
2	Injector	39.2	77.8	0.	0.	1736	1926	2056
3	Chamber	196.9	96.8	0.	0.	22451	42927	42927
4	Nozzle Extension	146.0	162.9			189778	233371	233371
5	Thrust Structure							
6	Ring and Gimbal Bearings	89.0	99.8	-1.6	0.	19907	7962	15557
7	Thrust Struts	6.3	86.0			900	272	1145
8	Controls and Valves							
9	Main Valves	81.3	67.2	0.	0.	1800	2135	2135
10	Electrical Harness	24.1	91.2	1.4	1.4	1967	4015	4015
11	Propellant Lines							
12	Main Lines	28.0	93.2	-0.3	0.4	9724	13209	12359
13	Valve Actuator Dump Line	2.3	99.2	5.2	4.4	497	590	507
14	Drain and Bleed Line	2.7	91.3	1.6	0.6	915	1122	1283
15	Screens, Orifices, Brackets	1.9	91.3	1.6	0.6	90	110	110
16	Thrust Vector Controls							
17	Pitch Actuator	28.7	87.2	-11.5	9.0	408	537	526
18	Yaw Actuator	28.7	90.0	12.0	-13.0	699	728	704
19	SUBTOTAL - DRY:	675.1	105.5	-0.1	-0.1	264309	992318	996955

*Reference datum is located 100 inches forward of the combustion chamber throat, on the engine centerline.

TABLE 4 (cont.)

DATE: 15 May 1964 Page 4 of 4 Item	Weight	Centers of Gravity x	y	z	Inertias I_{ox}	I_{oy}	I_{oz}
1 SUBTOTAL (From page 3)	675.1	105.5	-0.1	-0.1	264309	992318	996955
2 Less Ungimbaled Components:							
3 Ring and Gimbal Bearings	-33.0	99.8	-1.6	0.	-19902	-11724	-13272
4 Electrical Harness	-9.3	91.3	1.4	1.4	-690	-892	-892
5 Main Lines	-5.0	105.0	0.	0.	-1519	-1517	-1677
6 Valve Actuator and Dump	-.3	99.2	5.2	4.4	-154	-183	-157
7 Drain and Bleed Line	-1.0	91.3	1.6	.6	-90	-110	-110
8 Screens, Orifices, Brackets	-.9	91.3	1.6	.6	-43	-52	-52
9 Yaw Actuator	-27.0	90.0	12.0	-13.0	-366	-507	-507
10 Gimbaled Components - Dry (Yaw)	598.6	106.7	-0.6	-0.5	245761	996955	1001592
11 Gimbaled Propellants:							
12 Fuel	12.6	85.7	6.3	3.4	2594	3156	2525
13 Oxidizer	36.4	88.8	-9.2	-4.3	7042	8482	4600
14 Gimbaled Components - Wet (Yaw)	647.6	105.3	-.9	.2	259672	1015503	1020140
15 (Inertias About the Gimbal)					277805	1019725	1038273
16 Point (Yaw)							
17 Gimbaled Components - Dry (Yaw)	598.6	106.7	-0.6	-0.5	245761	996955	1001592
18 Pitch Actuator	-28.2	87.2	-11.5	9.0	-408	-537	-526
19 Gimbal Ring	-56.0	99.8	-1.6	0.0	-12526	-10919	-8354
20 Gimbaled Components - Dry(Pitch)	514.4	108.5	0.0	-1.0	225086	970550	976248
21 Fuel	12.6	85.7	6.3	3.4	2594	3156	2525
22 Oxidizer	36.4	88.8	-9.2	-4.3	7042	8482	4600
23 Gimbaled Components - Wet(Pitch)	563.4	106.7	-0.3	-0.5	234351	982329	983423
24 (Inertias About the Gimbal					259642	1007620	1008714
25 Point)(Pitch)							

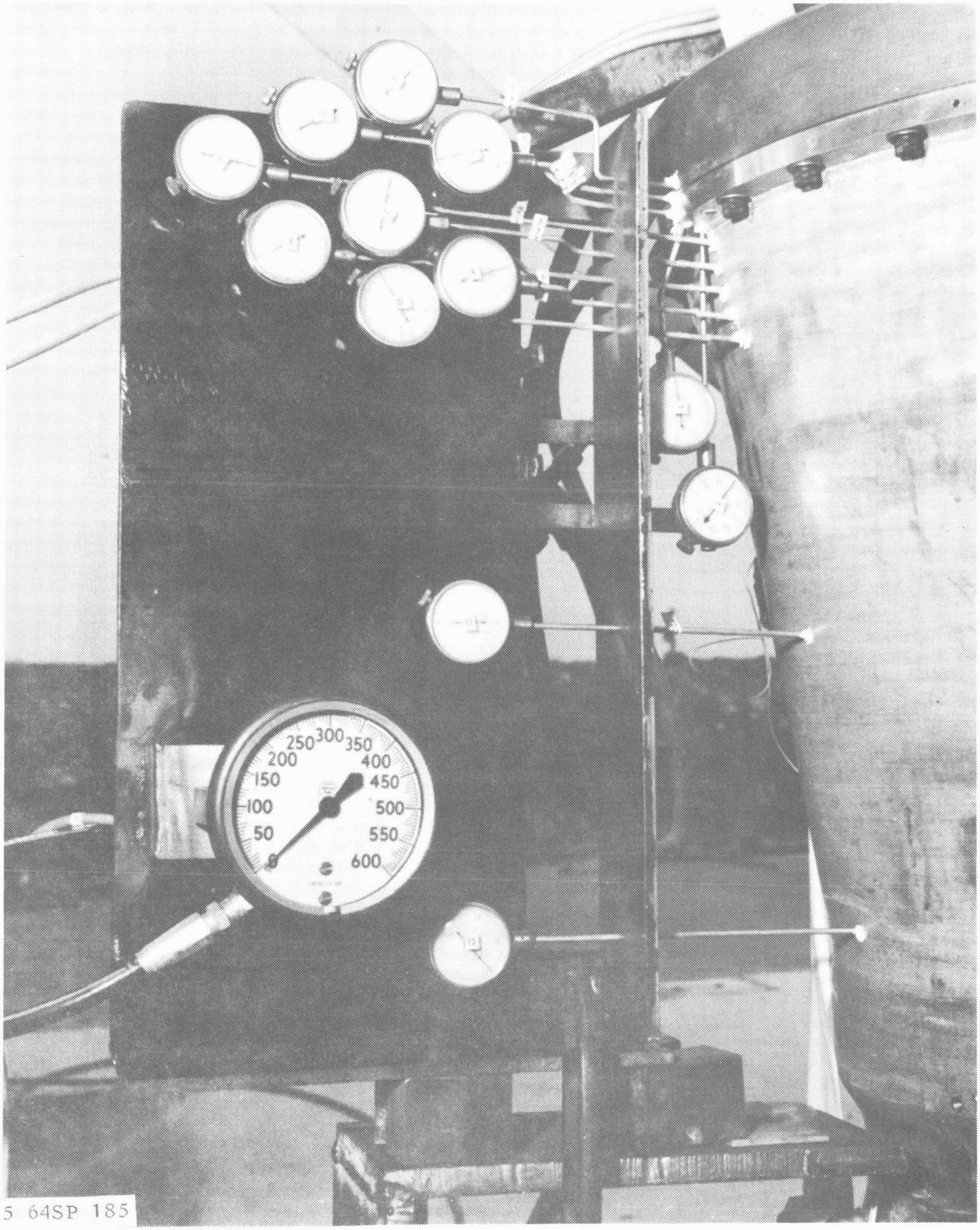
* Reference datum is located 100 inches forward of the combustion chamber throat on the engine centerline.

TABLE 5
FAILURE REPORT SUMMARY

Number	Date	Test No.	Part Tested	PN	SN	Remarks
251	4-13-64	1.2-03-DPA-022	Thrust Take-Out Strut	091047	A-44	Inspection of thrust takeout strut revealed two cracks. The cracks start at the base of the strut and run upward. One crack is approximately 1 in. long, and the other 3/8 in. long.
252	4-13-64	3.5-04-DPA-009 3.5-04-DPA-011	Engine Assembly	090142-7	0000006	Engine performance was not within specification limits.
253	4-11-64	---	Bipropellant Valve	085459-267	0000016	Leakage of bipropellant valve exceeded specification limits.
254	4-17-64	1.2-10-DAJ-003	Injector	705986	6-4-2	Fuel leakage during test was excessive. Inspection also noted a weld crack on the face of the injector.
255	4-18-64	---	Filter-Screen Assembly	091265-C	0000001	Assembly inspection revealed that the fuel filter screen was distorted. Tack welds on the three supports were broken. NOTE: This report was forwarded for information only. No failure analysis report will be written.
256	4-23-64	HTI 2-0514	Engine Assembly	090142-7F	0000006	Fifteen leaks noted during hydro-testing. Engine did not meet requirements of level "K" cleaning.

TABLE 5 (cont.)
FAILURE REPORT SUMMARY

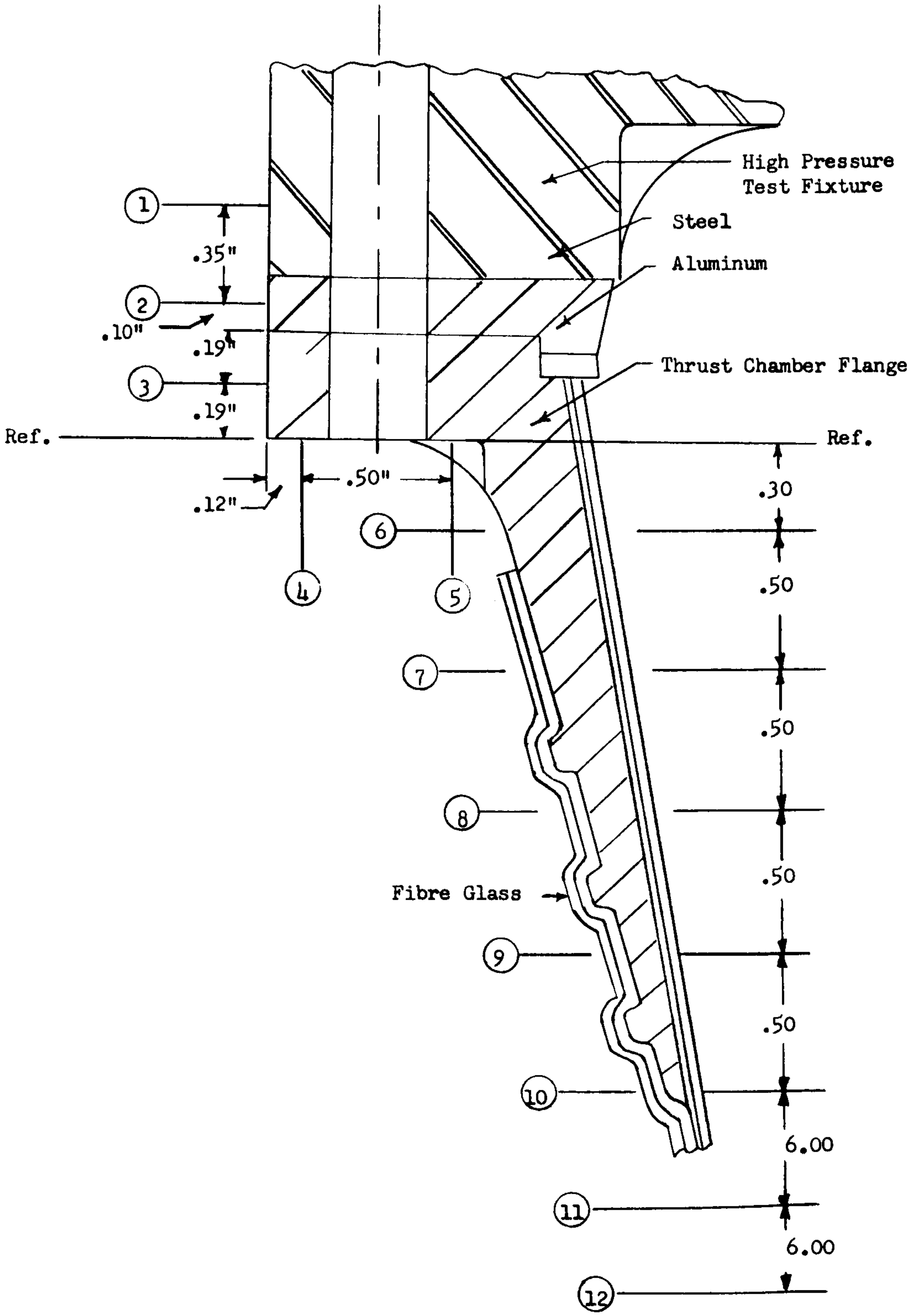
Number	Date	Test No.	Part Tested	PN	SN	Remarks
257	4-19-64	--	Valve Assembly	085459-267	0000016	Number 1 potentiometer was nonfunctional.
258	5-8-64	1.2-03-DPA-024	Engine Assembly	090270-87	0000007	Scheduled 5-sec test ran for a duration of 11.817 sec. Shutdown of test was accomplished by E.S.S.
259	4-22-64	---	Engine Assembly	090142-75	0000006	Engine components failed to meet acceptance test level "K" cleanliness.
260	5-1-64	1.2-03-DPA-023	Engine Assembly	090270-87	0000007	Review of records shows TCVPV 2 did not function.
261	5-6-64	1.2-10-DAJ-033	Injector	700082	AFF-34	A CSM occurred at 0.64 sec of intended 5.0 sec run.
262	5-5-64	1.2-10-DAJ-131	Injector	210382	AFF-32	Test was terminated at FS_1 + 1.436 of a scheduled 10-sec duration by a CSM shutdown.



External Dial Indicator Gage Arrangement

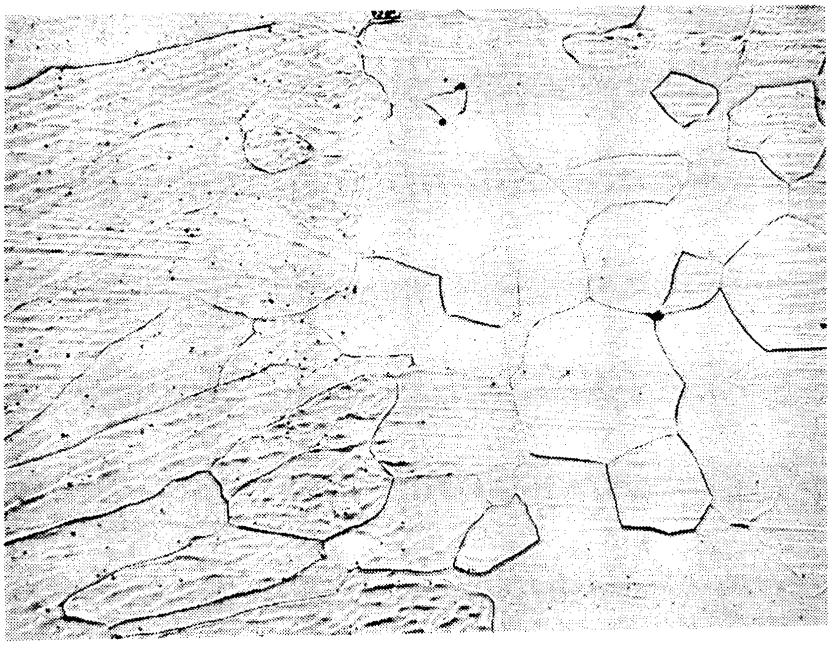
Figure 1

INSTRUMENTATION LOCATIONS
FOR THE STRUCTURAL PROOF TEST
ON THE APOLLO ABLATIVE THRUST
CHAMBER ASSEMBLY PN 704663-1

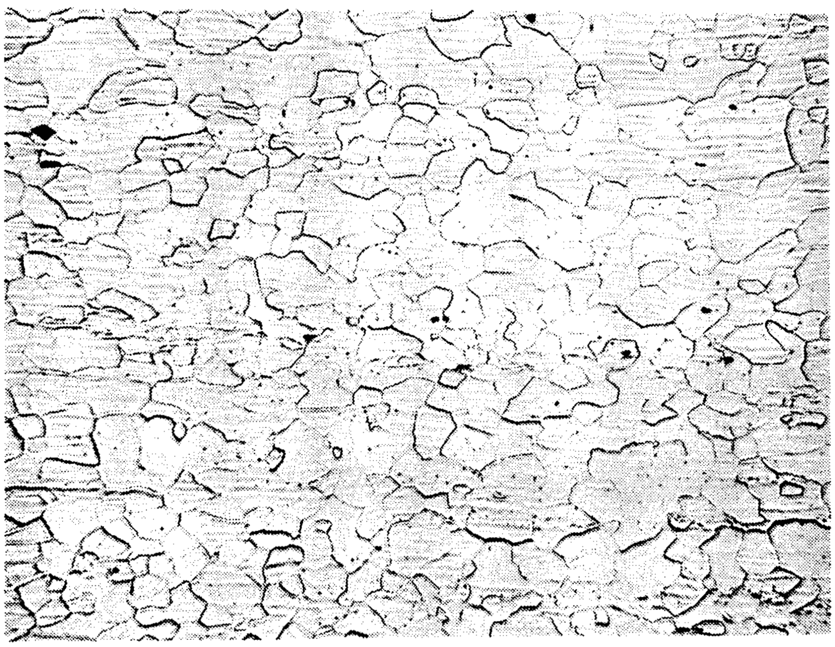


Sketch of Dial Indicator Locations

Figure 2



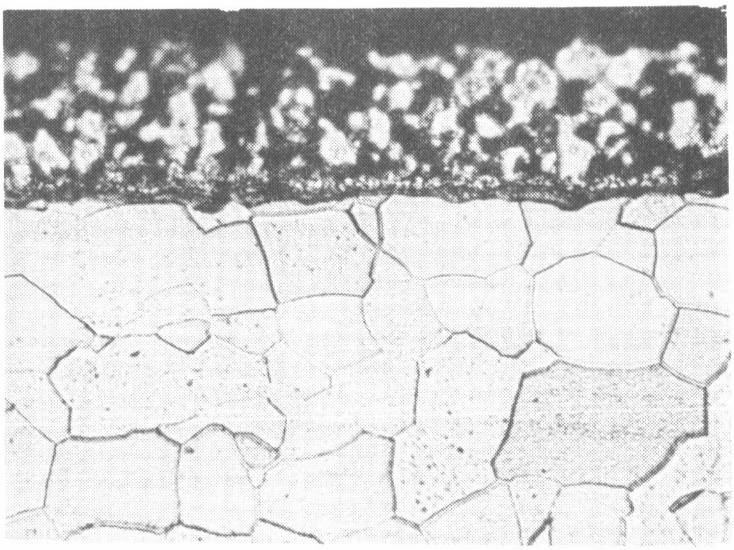
C-129 0.015 Fusion Zone and Heat Affected Zone (500X)



C-129 Parent Metal Adjacent to the Weld (500X)

Photomicrograph of C-129 Weld

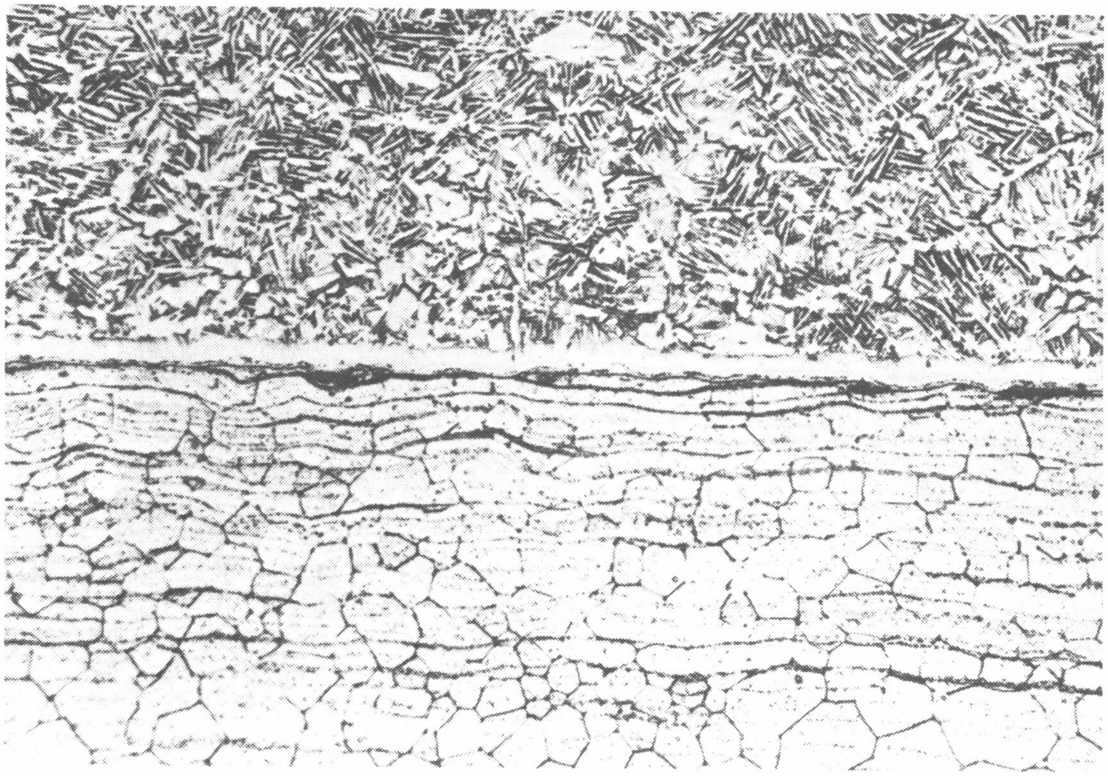
Figure 3



Fired 568 sec, Gas Side

C-103 Coated with NAA 85 Aluminide (750X Micrograph)

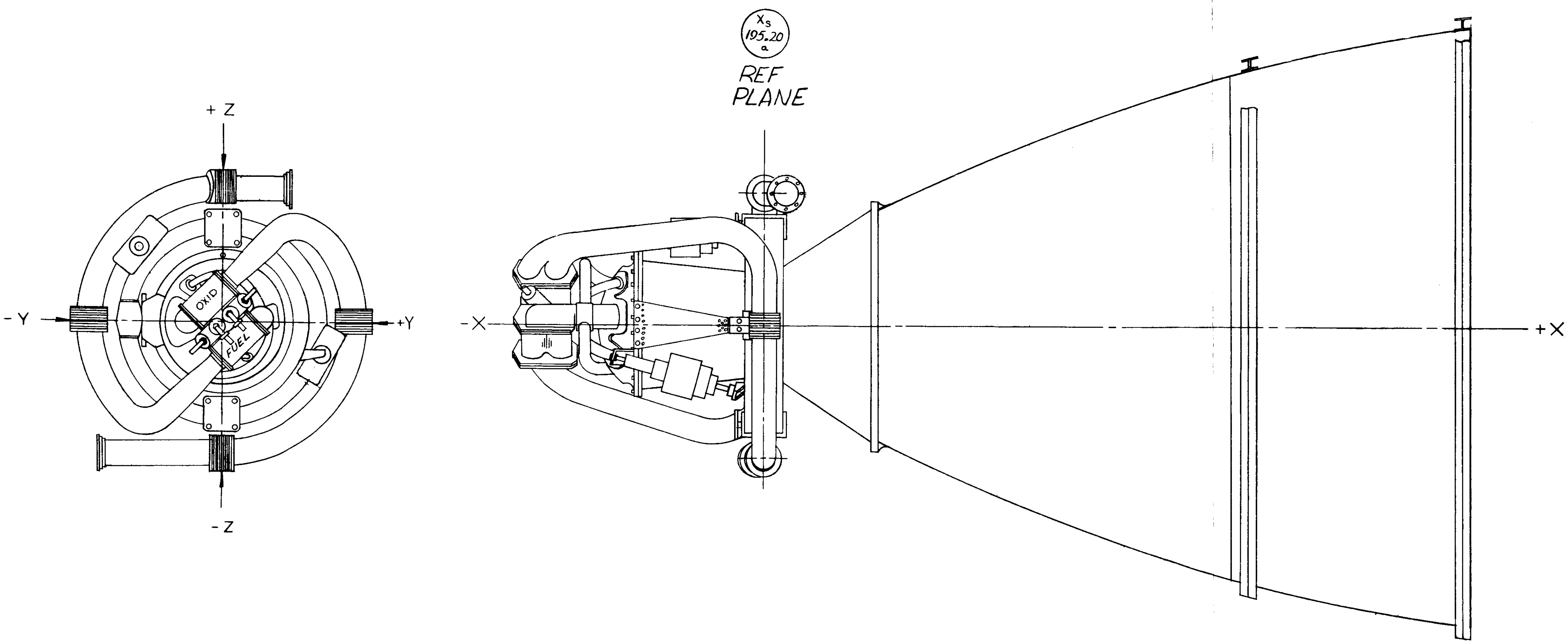
Figure 4



(500X)

Micrograph of Columbium-Titanium Resistance Seam-Weld

Figure 5



Sketch of Apollo Service Module Engine

Figure 6